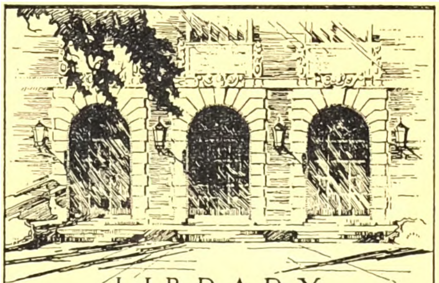
AVIATION
ELECTRICIAN'S MATE 3 & 2

BUREAU OF NAVAL PERSONNEL

NAVY TRAINING COURSE NAVPERS 10348-B



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PREFACE

This Navy Training Course is one of a series of training courses prepared especially for the Aviation Electrician's Mate. It is intended primarily to furnish useful information to those men of the U.S. Navy and Naval Reserve who are preparing for advancement to AE3 and AE2. Since all personnel seeking advancement to these levels are held responsible for the entire contents of this training course, a study guide has not been included. This course may also be used to improve any Aviation Electrician's Mate's daily working proficiency.

The Manual of Qualifications for Advancement in Rating, NavPers 18068-A, through change No. 1, has been used as a guide in the selection of content for this training course. Trainees should become familiar with the qualifications for advancement in rating prior to starting work on this course.

Of the 24 chapters in this training course, 23 are concerned with the technical aspects of the AE rating. Chapter 1 contains introductory information with which the trainee should familiarize himself before studying the other chapters.

Basic Electricity, NavPers 10086 (current edition), and Basic Electronics, NavPers 10087 (current edition), contain essential background information for the AE rating. Some other publications, the contents of which are related to the AE rating, are listed in the Reading List.

This training course has been prepared by the United States Navy Training Publications Center, Memphis, Tennessee, for the Bureau of Naval Personnel. Credit is given to the Aviation Electrician's Mate School, Jacksonville, Florida, and the Bureau of Naval Weapons for technical reviews and assistance.

1965 EDITION

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C., 20402 - Price $3.25

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THE UNITED STATES NAVY

GUARDIAN OF OUR COUNTRY

The United States Navy is responsible for maintaining control of the sea and is a ready force on watch at home and overseas, capable of strong action to preserve the peace or of instant offensive action to win in war.

It is upon the maintenance of this control that our country's glorious future depends; the United States Navy exists to make it so.

WE SERVE WITH HONOR

Tradition, valor, and victory are the Navy's heritage from the past. To these may be added dedication, discipline, and vigilance as the watchwords of the present and the future.

At home or on distant stations we serve with pride, confident in the respect of our country, our shipmates, and our families.

Our responsibilities sober us; our adversities strengthen us.

Service to God and Country is our special privilege. We serve with honor.

THE FUTURE OF THE NAVY

The Navy will always employ new weapons, new techniques, and greater power to protect and defend the United States on the sea, under the sea, and in the air.

Now and in the future, control of the sea gives the United States her greatest advantage for the maintenance of peace and for victory in war.

Mobility, surprise, dispersal, and offensive power are the keynotes of the new Navy. The roots of the Navy lie in a strong belief in the future, in continued dedication to our tasks, and in reflection on our heritage from the past.

Never have our opportunities and our responsibilities been greater.

CONTENTS

READING LIST

Training Publications for Advancement in Rating, NavPers 10052 (current series), has been used as a guide in preparing the following list of publications recommended for reading in conjunction with this training course:

Basic Electricity, NavPers 10086-A

Basic Electronics (Chapters 1-7, 17, 18, and 19), NavPers 10087-A

Basic Handtools, NavPers 10085-A

Basic Hydraulics, NavPers 16193 (current edition)

Basic Machines, NavPers 10624 (current edition)

Blueprint Reading and Sketching, NavPers 10077-B

CHAPTER 1

AVIATION ELECTRICIAN'S MATE RATING

This training course is designed to help you meet the professional (technical) qualifications for advancement to Aviation Electrician's Mate 3 or Aviation Electrician's Mate 2. The Aviation Electrician's Mate qualifications which were used as a guide in the preparation of this training course were current through the Change 1 revision of the Manual of Qualifications for Advancement in Rating, NavPers 18068-A.

Chapters 2 through 24 of this training course deal with the technical subject matter of the Aviation Electrician's Mate rating. Chapter 2 deals with safety precautions as they pertain to aviation electrical maintenance. Chapter 3 deals with the physics of heat, fluids, and gases. Power distribution and associated hardware are covered in chapter 4. Chapters 5 and 6 deal with aircraft lighting and storage batteries respectively. Chapters 7 and 8 discuss aircraft generators, motors, and inverters. Aircraft starters are covered in chapter 9. Chapter 10 deals with d-c voltage regulation and circuit protection. Chapters 11 and 12 deal with a-c generator regulation and a-c power systems, respectively. Aircraft ignition is the subject of chapter 13. Maintaining and troubleshooting circuits comprise the subject matter of chapter 14, and chapter 15 contains information on pressurization and cabin temperature control.

Chapter 16 discusses equipment circuits, while chapter 17 deals with aircraft electric-hydraulic systems. Chapter 18 covers aircraft compasses, and chapter 19 and 20 cover aircraft instrument systems. Chapter 21 contains information on automatic flight stabilization systems. Chapter 22 deals with handtools, and chapter 23 discusses line and shop maintenance and testing. Publications, records, and reports are covered in chapter 24.

The remainder of this chapter gives information on the enlisted rating structure, the Aviation Electrician's Mate rating, requirements and procedures for advancement in rating, and references that will help you in working for advancement and in performing your duties as an Aviation Electrician's Mate. This chapter includes information on how to make the best use of Navy Training Courses. Therefore, it is strongly recommended that you study this chapter carefully before beginning intensive study of the remainder of this training course.

THE ENLISTED RATING STRUCTURE

The present enlisted rating structure, established in 1957, includes three types of ratings—general ratings, service ratings, and emergency ratings.

General ratings identify broad occupational fields of related duties and functions. Some general ratings include service ratings; others do not. Both Regular Navy and Naval Reserve personnel may hold general ratings.

Service ratings identify subdivisions or specialties within a general rating. Although service ratings can exist at any petty officer level, they are most common at the P03 and P02 levels. Both Regular Navy and Naval Reserve personnel may hold service ratings.

Emergency ratings generally identify civilian occupational fields. Emergency ratings do not need to be identified as ratings in the peacetime Navy, but their identification is required in time of war.

AVIATION ELECTRICIAN'S MATE RATING

The Aviation Electrician's Mate rating is a general rating at pay grades E-4 through E-8. At paygrade E-9 the AE rating loses its identity and personnel in this rating advance, along with AXCS, AQCS, and ATCS to Master Chief Avionics Technician AVCM. Figure 1-1 illustrates all paths of advancement for an Airman Recruit to

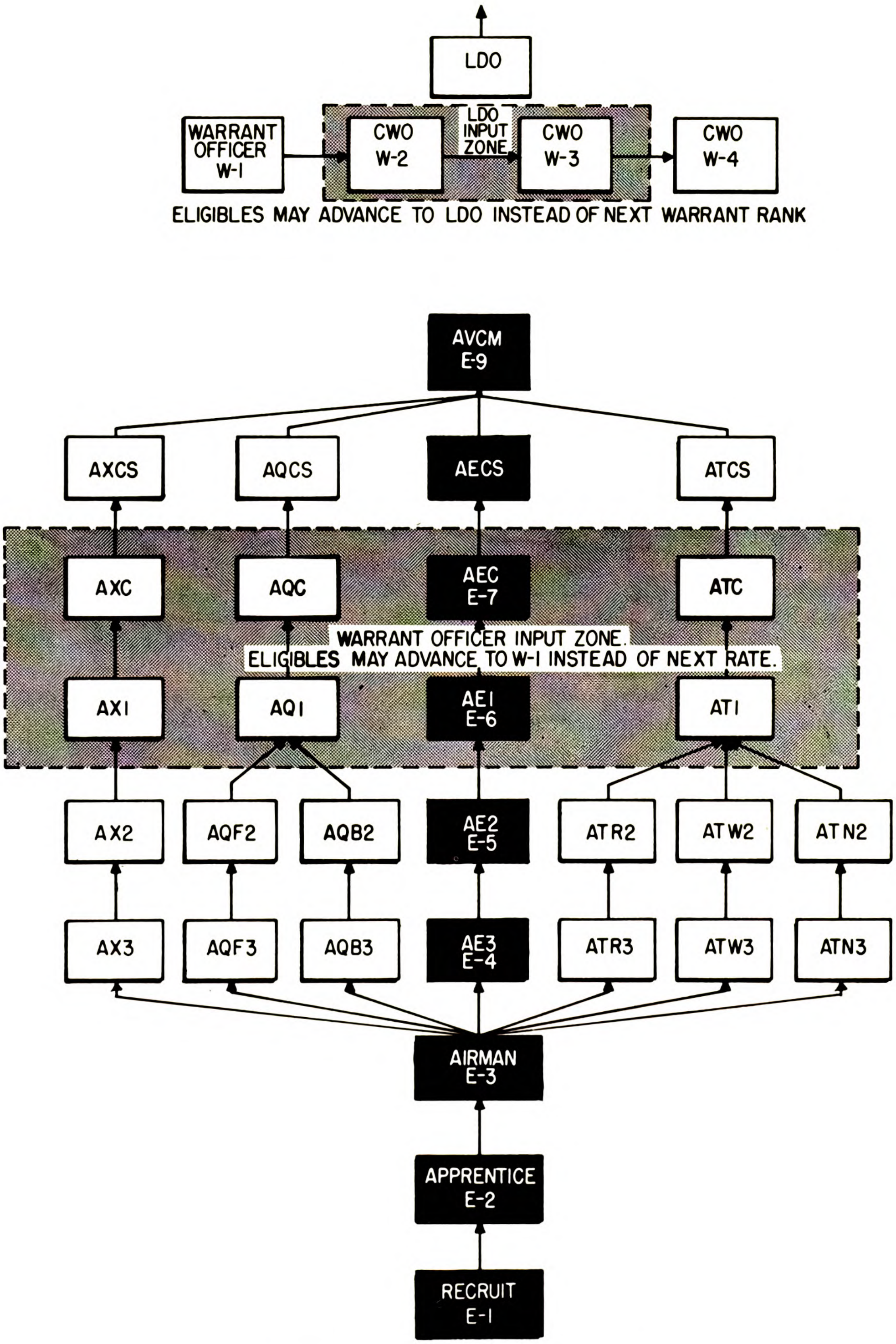


Figure 1-1.—Path of advancement.

Master Chief Avionics Technician, Warrant Officer (W-4), or to Limited Duty Officer. The advancement path through the AE rating is emphasized in figure 1-1. Shaded areas indicate career stages where qualified enlisted men may advance to Warrant Officer (W-1) and selected Warrant Officers may advance to Limited Duty Officer. Personnel in enlisted rates and warrant ranks not in a shaded area may advance only as indicated by the lines.

Aviation Electrician's Mates inspect and maintain aircraft electrical systems and equipment. As an Aviation Electrician's Mate Third Class or Second Class, your assignment possibilities cover a wide range of duties and responsibilities. Your specific duties will depend to a great extent upon the type of organization to which you are attached.

You most likely will be assigned to billets concerning the maintenance of aviation electrical and associated equipment. As an AE you may be attached to any one of the several types of aircraft maintenance activities.

In the aircraft squadron, your duties are concerned primarily with the avionics division of the maintenance department. You work under the supervision of the avionics division chief on all routine maintenance and minor repair of the electrical and associated equipments, and perform such other duties as may be assigned by the avionics officer. In some squadrons you may serve as a plane captain.

In the maintenance department of a naval air station, you may be assigned duties similar to those in an operating squadron. You may be assigned to a check crew or a troubleshooting crew.

On aircraft carriers and seaplane tenders, you may be assigned to crews who aid in incorporating required changes and modifications in squadron aircraft or who perform work involving shop tools and services.

One of the shore duty billets available to you as an AE2 may be assignment to the Naval Air Technical Training Center, Jacksonville, Florida as an instructor in the Aviation Electrician's Mate School.

Since you have been in pay grade E-3 or E-4 for some time, you realize that more leadership is required of the higher rates. Not only are you required to have superior knowledge, but you are also required to have the ability to handle personnel. This ability increases in importance as you advance through the various rates as a petty officer.

In General Order No. 21, the Secretary of the Navy outlined some of the most important aspects of naval leadership. By naval leadership is meant the art of accomplishing the Navy's mission through people. It is the sum of those qualities of intellect, of human understanding, and of moral character that enable a man to inspire and to manage a group of people successfully. Effective leadership, therefore, is based on personal example, good management practices, and moral responsibility. The term leadership includes all three of these elements.

The current Navy Leadership Program is designed to keep the spirit of General Order No. 21 ever before you. If the threefold objective is carried out effectively in every command, the program will make of you a better leader of men in your present billet and in your future assignments. As you advance up the leadership ladder, more and more your worth to the Navy will be judged on the basis of the amount of efficient work you obtain from your subordinates rather than how much of the actual work you do yourself.

For information on the practical application of leadership and supervision, study Military Requirements for Petty Officer 3 & 2, NavPers 10056-A.

ADVANCEMENT IN RATING

Some of the rewards of advancement in rating are easy to see. You get more pay. Your job assignments become more interesting and more challenging. You are regarded with greater respect by officers and enlisted personnel. You enjoy the satisfaction of getting ahead in your chosen Navy career.

The advantages of advancing in rating are not yours alone. The Navy also profits. Highly trained personnel are essential to the functioning of the Navy. By each advancement in rating, you increase your value to the Navy in two ways: First, you become more valuable as a technical specialist in your own rating; and second, you become more valuable as a person who can train others and thus make far-reaching contributions to the entire Navy.

HOW TO QUALIFY FOR ADVANCEMENT

What must you do to qualify for advancement in rating? The requirements may change from time to time, but usually you must:

1. Have a certain amount of time in your present grade.

2. Complete the required military and professional training courses.

3. Demonstrate your ability to perform all the practical requirements for advancement by completing the Record of Practical Factors, NavPers 760.

4. Be recommended by your commanding officer, after the petty officers and officers supervising your work have indicated that they consider you capable of performing the duties of the next higher rate.

5. Demonstrate your knowledge by passing a written examination on military requirements and professional qualifications.

Some of these general requirements may be modified in certain ways. Figure 1-2 gives a more detailed view of the requirements for advancement of active duty personnel; figure 1-3 gives this information for inactive duty personnel.

Remember that the requirements for advancement can change. Check with your educational services office to be sure that you know the most recent requirements.

Advancement in rating is not automatic. After you have met all the requirements, you are eligible for advancement. You will actually be advanced in rating only if you meet all the requirements (including making a high enough score on the written examination) and if the quotas for your rating permit your advancement.

HOW TO PREPARE FOR ADVANCEMENT

What must you do to prepare for advancement in rating? You must study the qualifications for advancement, work on the practical factors, study the required Navy Training Courses, and study other material that is required for advancement in your rating. To prepare for advancement, you will need to be familiar with the "Quals" Manual, the Record of Practical Factors, NavPers 760, Training Publications for Advancement in Rating, NavPers 10052 (Series), and applicable Navy Training Courses. The following sections describe them and give you some practical suggestions on how to use them in preparing for advancement.

The "Quals" Manual

The Manual of Qualifications for Advancement in Rating, NavPers 18068-A (with changes), gives the minimum requirements for advancement to each rate within each rating. This manual is usually called the "Quals" Manual, and the qualifications themselves are often called "quals." The qualifications are of two general types: military requirements, and professional (or technical) qualifications.

Military requirements apply to all ratings rather than to any one particular rating. Military requirements for advancement to third class and second class petty officer rates deal with military conduct, naval organization, military justice, security, watch standing, and other subjects which are required of petty officers in all ratings.

Professional qualifications are technical or professional requirements that are directly related to the work of each rating.

Both the military requirements and the professional qualifications are divided into subject matter groups; then, within each subject matter group, they are divided into practical factors and knowledge factors. Practical factors are things you must be able to DO. Knowledge factors are things you must KNOW in order to perform the duties of your rating.

The qualifications for advancement in your rating are available in your educational services office. Also, when you take the advancement examination, you will retain a TEAR-OFF SHEET containing the "quals" for your rating. Study these qualifications and the military requirements carefully. The written examination for advancement in rating will contain questions relating to the practical factors and the knowledge factors of both the military requirements and the professional qualifications. If you are working for advancement to second class, remember that you may be examined on third class qualfications as well as on second class qualifications.

The "Quals" Manual is kept current by means of changes. "Quals" for a rating change from time to time. Never trust any set of "quals" until you have checked the change number against an up-to-date copy of the "Quals" Manual. Be sure you have the latest revision.

Record of Practical Factors

Before you can take the Navy-wide examination for advancement in rating, there must be an entry in your service record to show that you have qualified in the practical factors of both the military requirements and the professional qualifications. A special form known as the Record of Practical Factors, NavPers 760, is used to keep a record of your practical factor

ACTIVE DUTY ADVANCEMENT REQUIREMENTS

REQUIREMENTS *	E1 to E2	E2 to E3	E3 to E4	E4 to E5	E5 to E6	† E6 to E7	† E7 to E8	† E8 to E9
SERVICE	4 mos. service—or completion of recruit training.	6 mos. as E-2.	6 mos. as E-3.	12 mos. as E-4.	24 mos. as E-5.	36 mos. as E-6.	48 mos. as E-7. 8 of 11 years total service must be enlisted.	24 mos. as E-8. 10 of 13 years total service must be enlisted.
SCHOOL	Recruit Training.		Class A for PR3, DT3, PT3, AME 3, HM 3			Class B for AGCA, MUCA, MNCA.	Must be permanent appointment.	
PRACTICAL FACTORS	Locally prepared check-offs.	Records of Practical Factors, NavPers 760, must be completed for E-3 and all PO advancements.						
PERFORMANCE TEST			Specified ratings must complete applicable performance tests before taking examinations.					
ENLISTED PERFORMANCE EVALUATION	As used by CO when approving advancement.		Counts toward performance factor credit in advancement multiple.					
EXAMINATIONS	Locally prepared tests.		Navy-wide examinations required for all PO advancements.				Navy-wide, selection board, and physical.	
NAVY TRAINING COURSE (INCLUDING MILITARY REQUIREMENTS)		Required for E-3 and all PO advancements unless waived because of school completion, but need not be repeated if identical course has already been completed. See NavPers 10052 (current edition).					Correspondence courses and recommended reading. See NavPers 10052 (current edition).	
AUTHORIZATION	Commanding Officer		U.S. Naval Examining Center			Bureau of Naval Personnel		
	TARS attached to the air program are advanced to fill vacancies and must be approved by CNARESTRA.							

* All advancements require commanding officer's recommendation.
† 2 years obligated service required.

Figure 1-2.—Active duty advancement requirements.

INACTIVE DUTY ADVANCEMENT REQUIREMENTS

REQUIREMENTS *	FOR THESE DRILLS PER YEAR	E1 to E2	E2 to E3	E3 to E4	E4 to E5	E5 to E6	E6 to E7	E8	E9
TOTAL TIME IN GRADE	48	6 mos.	6 mos.	15 mos.	18 mos.	24 mos.	36 mos.	48 mos.	24 mos.
	24	9 mos.	9 mos.	15 mos.	18 mos.	24 mos.	36 mos.	48 mos.	24 mos.
	NON-DRILLING	12 mos.	24 mos.	24 mos.	36 mos.	48 mos.	48 mos.		
DRILLS ATTENDED IN GRADE †	48	18	18	45	54	72	108	144	72
	24	16	16	27	32	42	64	85	32
TOTAL TRAINING DUTY IN GRADE †	48	14 days	14 days	14 days	14 days	28 days	42 days	56 days	28 days
	24	14 days	14 days	14 days	14 days	28 days	42 days	56 days	28 days
	NON-DRILLING	None	None	14 days	14 days	28 days	28 days		
PERFORMANCE TESTS				Specified ratings must complete applicable performance tests before taking examination.					
PRACTICAL FACTORS (INCLUDING MILITARY REQUIREMENTS)		Record of Practical Factors, NavPers 760, must be completed for all advancements.							
NAVY TRAINING COURSE (INCLUDING MILITARY REQUIREMENTS)		Completion of applicable course or courses must be entered in service record.							
EXAMINATION		Standard exams are used where available, otherwise locally prepared exams are used.						Standard EXAM, Selection Board, and Physical.	
AUTHORIZATION		District commandant or CNARESTRA					Bureau of Naval Personnel		

* Recommendation by commanding officer required for all advancements.
† Active duty periods may be substituted for drills and training duty.

Figure 1-3.—Inactive duty advancement requirements.

qualifications. This form is available for each rating. The form lists all practical factors, both military and professional. As you demonstrate your ability to perform each practical factor, appropriate entries are made in the DATE and INITIALS columns.

Changes are made periodically to the Manual of Qualifications for Advancement in Rating, and revised forms of NavPers 760 are provided when necessary. Extra space is allowed on the Record of Practical Factors for entering additional practical factors as they are published in changes. The Record of Practical Factors also provides space for recording demonstrated proficiency in skills which are within the general scope of the rating but which are not identified as minimum qualifications for advancement.

If you are transferred before you qualify in all practical factors, NavPers 760 should be forwarded with your service record to your next duty station. You can save yourself a lot of trouble by making sure that this form is actually inserted in your service record before you are transferred. If the form is not in your service record, you may be required to start all over again and requalify in the practical factors which have already been checked off.

A second copy of the Record of Practical Factors should be made available to each man in pay grades E-2 through E-8 for his personal record and guidance.

NavPers 10052

Training Publications for Advancement in Rating, NavPers 10052 (series), is a very important publication for anyone preparing for advancement in rating. This bibliography lists required and recommended Navy Training Courses and other reference material to be used by personnel working for advancement in rating. NavPers 10052 is revised and issued once each year by the Bureau of Naval Personnel. Each revised edition is identified by a letter following the NavPers number. When using this publication, be sure that you have the most recent edition.

If extensive changes in qualifications occur in any rating between the annual revisions of NavPers 10052, a supplementary list of study material may be issued in the form of a BuPers Notice. When you are preparing for advancement, check to see whether changes have been made in the qualifications for your rating. If changes have been made, see if a BuPers Notice has been issued to supplement NavPers 10052 for your rating.

The required and recommended references are listed by rate level in NavPers 10052. If you are working for advancement to third class, study the material that is listed for third class. If you are working for advancement to second class, study the material that is listed for second class. Remember that you are also responsible for the references listed at the third class level.

In using NavPers 10052, you will notice that some Navy Training Courses are marked with an asterisk (*). Any course marked in this way is MANDATORY—that is, it must be completed at the indicated rate level before you can be eligible to take the Navy-wide examination for advancement in rating. Each mandatory course may be completed by passing the appropriate enlisted correspondence course that is based on the mandatory training course, passing locally prepared tests based on the information given in the training course, or in some cases, successfully completing an appropriate Class A school.

Do not overlook the section of NavPers 10052 which lists the required and recommended references relating to the military requirements for advancement. Personnel of all ratings must complete the mandatory military requirements training course for the appropriate rate level before they can be eligible to advance in rating.

The references in NavPers 10052 which are recommended but not mandatory should also be studied carefully. All references listed in NavPers 10052 may be used as source material for the written examinations at the appropriate rate levels.

Navy Training Courses

There are two general types of Navy Training Courses. Rating courses (such as this one) are prepared for most enlisted ratings. A rating training course gives information that is directly related to the professional qualifications of one rating. Subject matter courses or basic courses give information that applies to more than one rating.

Navy Training Courses are revised from time to time to keep them up to date technically. The revision of a Navy Training Course is identified by a letter following the NavPers number. You can tell whether any particular copy of a Navy Training Course is the latest edition by checking the NavPers number and the letter following this number in the most recent edition of List of

Training Manuals and Correspondence Courses, NavPers 10061. (NavPers 10061 is actually a catalog that lists current training courses and correspondence courses; you will find this catalog useful in planning your study program.)

Navy Training Courses are designed to help you prepare for advancement in rating. The following suggestions may help you to make the best use of this course and other Navy training publications when you are preparing for advancement in rating.

1. Study the military requirements and the professional qualifications for your rating before you study the training course, and refer to the "quals" frequently as you study. Remember, you are studying the training course in order to meet these "quals."

2. Set up a regular study plan. If possible, schedule your studying for a time of day when you will not have too many interruptions or distractions.

3. Before you begin to study any part of the training course intensively, become familiar with the entire course. Read the preface and the table of contents. Check through the index. Look at the appendixes. Thumb through the course without any particular plan, looking at the illustrations and reading bits here and there as you see things that interest you.

4. Look at the training course in more detail, to see how it is organized. Look at the table of contents again. Then, chapter by chapter, read the introduction, the headings, and the subheadings. This will give you a clear picture of the scope and content of the course. As you look through the course in this way, ask yourself some questions: What do I need to learn about this? What do I already know about this? How is this information related to information given in other chapters? How is this information related to the qualifications for advancement in rating?

5. When you have a general idea of what is in the training course and how it is organized, fill in the details by intensive study. In each study period, try to cover a complete unit—it may be a chapter, a section of a chapter, or a subsection. If you know the subject well, or if the material is easy, you can cover quite a lot at one time. Difficult or unfamiliar material will require more study time.

6. In studying any one unit—chapter, section, or subsection—write down the questions that occur to you. Many people find it helpful to make a written outline of the unit as they study, or at least to write down the most important ideas.

7. As you study, relate the information in the training course to the knowledge you already have. When you read about a process, a skill, or a situation, try to see how this information ties in with your own past experience.

8. When you have finished studying a unit, take time out to see what you have learned. Look back over your notes and questions. Maybe some of your questions have been answered, but perhaps you still have some that are not answered. Without referring to the training course, write down the main ideas that you have learned from studying this unit. Do not quote the course. If you cannot give these ideas in your own words, the chances are that you have not really mastered the information.

9. Use Enlisted Correspondence Courses whenever you can. The correspondence courses are based on Navy Training Courses or on other appropriate texts. As mentioned before, completion of a mandatory Navy Training Course can be accomplished by passing an Enlisted Correspondence Course based on the Navy Training Course. You will probably find it helpful to take other correspondence courses, as well as those based on mandatory training courses. Taking a correspondence course helps you to master the information given in the training course, and also helps you see how much you have learned.

10. Think of your future as you study Navy Training Courses. You are working for advancement to third class or second class right now, but someday you will be working toward higher rates. Anything extra that you can learn now will help you both now and later.

SOURCES OF INFORMATION

One of the most useful things you can learn about a subject is how to find out more about it. No single publication can give you all the information you need to perform the duties of your rating. You should learn where to look for accurate, authoritative, up-to-date information on all subjects related to the military requirements for advancement and the professional qualifications of your rating.

Some of the publications described in this chapter are subject to change or revision from time to time—some at regular intervals, others as the need arises. When using any publication that is subject to change or revision, be sure that

you have the latest edition. When using any publication that is kept current by means of changes, be sure you have a copy in which all official changes have been made. Studying canceled or obsolete information will not help you to do your work or to advance in rating; it is likely to be a waste of time, and may even be seriously misleading.

Training films available to naval personnel are a valuable source of information on many technical subjects. A selected list of training films that may be useful to you is given in appendix IV of this training course. Other films that may be of interest are listed in the United States Navy Film Catalog, NavPers 10000 (Revised), and the Cumulative Supplement to U.S. Navy Film Catalog, NavWeps 10-1-772.

BuPers publications that you will need to study or refer to as you prepare for advancement have already been discussed earlier in this chapter. Additional BuPers publications that you may find useful are as follows:

Basic Electricity, NavPers 10086-A
Basic Electronics, NavPers 10087-A
Basic Handtools, NavPers 10085-A
Basic Hydraulics, NavPers 16193
Basic Machines, NavPers 10624
Blueprint Reading and Sketching, NavPers 10077-A
Mathematics, Vol. 1, NavPers 10069-B
Mathematics, Vol. 2, NavPers 10071-A

In addition, you may find it useful to consult some of the Navy Training Courses prepared for other Group IX (Aviation) ratings. Reference to these training courses will add to your knowledge of the duties of other men in the field of aviation.

A number of publications issued by the Bureau of Naval Weapons will be of interest to you. The Naval Aircraft Maintenance Program, BuWeps Instruction 4700.2 (latest series), for example, is a publication with which you should be thoroughly familiar. There are also BuWeps technical publications covering the various aviation electrical equipment and related equipment to which you must refer in the actual maintenance which you will be required to perform. While you do not need to know everything that is contained in these publications, you should know how to find the necessary information in them.

CHAPTER 2

SAFETY

When working with electrical equipment there is one rule that must be strongly stressed: safety first. Whether you are working in the shop, on the line, or during a flight, you should follow prescribed safety procedures. You must be aware of the many dangers that are associated with this type of work. Among the possible hazards of this work are electrical fires and harmful gases, which are sometimes generated by faulty electrical and electronic devices. The most common danger that you will encounter is that of the high voltages that are present in much equipment. Also, when working with aircraft, there is the possibility of falling from the aircraft, of being burned by a jet blast, or of being struck by propeller or rotor blades.

Because of these dangers, the electrician should regard the formation of safe and intelligent work habits as being equal in importance to the development of his knowledge of electrical equipment. One of his primary objectives should be to become a safety specialist, trained in recognizing and correcting dangerous conditions, and in avoiding unsafe acts.

Under the heading "Basic Precepts," the United States Navy Safety Precautions (OpNav 34P1) makes the following statement:

"Most accidents which occur in noncombat operations can be prevented if the full cooperation of personnel is gained and vigilance is exercised to eliminate unsafe acts."

This publication then gives the following general safety rules which apply to personnel in all types of activities:

"Each individual concerned shall strictly observe all safety precautions applicable to his work or duty.

"a. REPORTING UNSAFE CONDITIONS. Each individual concerned shall report any unsafe condition, or any equipment or material which he considers to be unsafe.

"b. WARNING OTHERS. Each individual concerned shall warn others whom he believes to be endangered by known hazards or by failure to observe safety precautions.

"c. PERSONAL PROTECTIVE EQUIPMENT. Each individual concerned shall wear or use protective clothing or equipment of the type approved for the safe performance of his work or duty.

"d. REPORT OF INJURY OR ILL HEALTH. All personnel shall report to their supervisors any injury or evidence of impaired health occurring in the course of work or duty.

"e. EMERGENCY CONDITIONS. In the event of an unforeseen hazardous occurrence, each individual concerned is expected to exercise such reasonable caution as is appropriate to the situation."

The safety precautions which apply to the work and duty of Aviation Electrician's Mates include those pertaining to working in and around aircraft, in the electric or battery shop, precautions against electric shock and electric burns, and those which concern the proper use of handtools and small power tools. In addition to these, it is also necessary that the electrician know the authorized methods for dealing with fires of electric origin, for treating burns, and for giving artificial respiration to persons suffering from electric shock.

The Navy Training Courses Airman, NavPers 10307-B, and Standard First Aid Training Course, NavPers 10081-A, contain safety information with which you should be familiar. It is recommended that you acquaint or reacquaint yourself with the sections of Airman that deal with safety as it relates to naval aviation. The Standard First Aid Training Course is designed as a basic reference in the field of first aid; since all naval personnel are required to possess a knowledge of the principles of first aid, you should become familiar with this training course.

PRECAUTIONS REGARDING AIRCRAFT

Safety on the flight line is of paramount importance to the AE. Any type of moving machinery is dangerous. Therefore, the AE must be doubly alert when working around aircraft that are being turned up. When working with propeller type aircraft, the first general precaution that you must observe is: Beware of propellers. The propellers on engines that are being turned up are hard to see; therefore, you should develop a habit of staying clear of the propeller at all times.

Jet aircraft present basically the same type of problem in that the AE should stay clear of the intake and exhaust. Due to the tremendous suction of the intake, the area around the aircraft must be kept clear of gear and debris. Foreign object damage (FOD) is not only dangerous, it is costly to the squadron. When working with jet aircraft, objects and clothing that may be sucked into the intake should not be carried on the line. While working on the flight line, the AE should observe the standard operating procedure of safety established by the squadron. Particular emphasis should be placed on the wearing of ear protectors. However, a word of caution: When wearing ear protectors, it is extremely hard to tell when a particular jet on the line is being turned-up. It is therefore very easy to walk into the blast zone of the aircraft.

Do not smoke or bring any type of open flame within 50 feet of any parked aircraft. Remember that vapor from aviation fuel can be ignited in a number of ways—by lighted cigarettes, by static discharges, and by sparks from tools or from electrical and electronic equipment. Electrical equipment installed in aircraft should not be operated during fueling of the aircraft, or within 50 feet of any such fueling operation.

Storage batteries should not be disconnected or removed from their circuits within any aircraft immediately after flight without first ventilating the container to allow any gas accumulated during charging to escape. An inspection should be made before removal to insure the opening of all switches, to prevent the possibility of a spark being generated at the terminal of the battery when the connection is broken.

During refueling, radar equipment should not be operated within 75 feet of the aircraft, and no electrical apparatus supplied by outside power (such as droplights and floodlights) should be operated in or near it.

See that combustible materials such as rags and clean waste are stowed in covered metal containers. Used waste and rags should never be discarded near aircraft but should always be put in plainly marked metal receptacles.

SAFETY IN FLIGHT

In the air the pilot in command of the aircraft is responsible for the safe and orderly conduct of the flight. When the electrician wishes to operate electrical equipment or to make any unusual repairs on the equipment, he must always request permission from the pilot before proceeding.

GENERAL PRECAUTIONS

Because of the possibility of injury to personnel, the danger of fire, and possible damage to material, all repair and maintenance work on both electronic and electrical equipment should be performed only by duly authorized and assigned persons.

When any electrical equipment is to be overhauled or repaired, the main supply switches or cutout switches in each circuit from which power could possibly be fed should be secured in the open position and tagged. The tag should read, "This circuit was ordered open for repairs and shall not be closed except by direct order of. . ." (usually the person directly in charge of the repairs). After the work has been completed, the tag (or tags) should be removed by the same person.

The covers of fuse boxes and junction boxes should be kept securely closed except when work is being performed. Safety devices such as interlocks, overload relays, and fuses should never be altered or disconnected except for replacements. Safety or protective devices should never be changed or modified in any way without specific authorization.

Fuses should be removed and replaced only after the circuit has been deenergized. When a fuse blows, it should be replaced only with a fuse of the same current rating. When possible, the circuit should be carefully checked before making the replacement, since the burned-out fuse is often the result of circuit fault.

PRECAUTIONS REGARDING MATERIALS AND EQUIPMENT

Insofar as is practicable, repair work on energized circuits should not be undertaken. When repairs on operating equipment must be made because of emergency conditions, or when such repairs are considered to be essential, the work should be done only by experienced personnel, and if possible, under the supervision of the senior petty officer of the electrical shop. Every known safety precaution should be carefully observed. Ample light for good illumination should be provided; the worker should be insulated from ground with some suitable nonconducting material such as several layers of dry canvas, dry wood, or a rubber mat of approved construction. The worker should, if possible, use only one hand in accomplishing the necessary repairs. Helpers should be stationed near the main switch or the circuit breaker so that the equipment can be deenergized immediately in case of emergency. A man qualified in first aid for electric shock should stand by during the entire period of the repair.

HIGH-VOLTAGE PRECAUTIONS

Personnel should never work alone near high-voltage equipment. Tools and equipment containing metal parts should not be used in any area within 4 feet of high-voltage circuits or any electric wiring having exposed surfaces. The handles of all metal tools, such as pliers and cutters, should be covered with rubber insulating tape. (The use of plastic or cambric sleeving or of friction tape alone for this purpose is prohibited.)

Before touching a capacitor which is connected to a deenergized circuit, or which is disconnected entirely, short-circuit the terminals to make sure that the capacitor is completely discharged. Grounded shorting prods should be permanently attached to workbenches where electrical devices are regularly serviced.

Do not work on any type of electrical apparatus with wet hands or while wearing wet clothing, and do not wear loose or flapping clothing. The use of thin-soled shoes with metal plates or hobnails is prohibited. Safety shoes with nonconducting soles should be worn if available. Flammable articles, such as celluloid cap visors, should not be worn.

When working on electrical or electronic apparatus, you should first remove all rings, wristwatches, bracelets, and similar metal items. Care should be taken that the clothing does not contain exposed zippers, metal buttons, or any type of metal fastener.

Warning signs and suitable guards should be provided to prevent personnel from coming into accidental contact with high voltages.

LOW-VOLTAGE PRECAUTIONS

Most people never realize the dangers of low-voltage electric shock. These hazards are ever present, and it is surprising how dangerous they can be. Defective handtools and improper usage can be corrected, but some hazards will always exist. An awareness of their existence seems to be the answer. In general, beware of any voltage greater than about 15 volts.

DEGREE OF SHOCK

The amount of current that may pass through the body without danger depends on the individual and the current quantity, the type, path, and length of contact time.

Body resistance varies from 1,000 to 500,000 ohms for unbroken, dry skin. Resistance is lowered by moisture and high voltage, and is highest with dry skin and low voltage. Breaks, cuts, or burns may lower body resistance to 200 ohms. A current of 1 milliampere can be felt and will cause a person to avoid it. Five milliamperes is about the highest current safe for the average body. If the palm of the hand makes contact with the conductor, a current of about 12 milliamperes will tend to cause the hand muscles to contract, freezing the body to the conductor. Such a shock may or may not cause serious damage, depending on the contact time and your physical condition, particularly the condition of your heart. A current of only 25 milliamperes has been known to be fatal; 100 milliamperes is likely to be fatal.

Due to the physiological and chemical nature of the human body, five times more d-c current than a-c current is needed to freeze the same body to a conductor. Also, 60-cycle a-c current is about the most dangerous frequency.

The damage from shock is also proportional to the number of vital organs transversed, especially the percentage of current that reaches the heart. Approximately one-tenth of the current passing from the right shoulder to the left

leg will reach the heart; a greater percentage will reach the heart if current passes through the left shoulder.

ELECTRICAL FIRES

In case of electrical fires, the following steps should be taken:

1. Deenergize the circuit.
2. Call the fire department if the fire is in a hangar or a shop (aboard ship called the OOD).
3. Control or extinguish the fire, using the correct type of fire extinguisher.
4. Make reports as required by local directives.

For combating electrical fires, use a CO_2 (carbon dioxide) fire extinguisher and direct it toward the base of the flame. Carbon tetrachloride should never be used for firefighting since it changes to phosgene (a war gas) upon contact with hot metal, and even in open air this gas creates a hazardous condition. The application of water to electrical fires is dangerous; and foam type fire extinguishers should not be used since the foam is electrically conductive.

In case of cable fires in which the inner layers of insulation or insulation covered by armor are burning, the only positive method of preventing the fire from running the length of the cable is to cut the cable and separate the two ends.

BATTERY SAFETY PRECAUTIONS

The principal hazard in connection with batteries is the danger of acid burns when refilling or when handling them. These burns can be prevented by the proper use of eyeshields, rubber gloves, rubber aprons, and rubber boots with nonslip soles. Rubber boots and apron need be worn only when batteries are being refilled. It is a good practice, however, to wear the eyeshield whenever working around batteries to prevent the possibility of acid burns of the eyes. Wood slat floorboards, if kept in good condition, are helpful in preventing slips and falls as well as electric shock from the high-voltage side of charging equipment.

Another hazard is the danger of explosion due to the ignition of hydrogen gas given off during battery charging operation. This is especially true where the accelerated charging method is used. Open flames or smoking should not be permitted in the battery charging room, and the charging rate should be held at a point that will prevent the rapid liberation of hydrogen gas. Manufacturers' recommendations as to the charging rates for various size batteries should be closely followed and a shop exhaust system should be used.

Particular care should be taken by electricians to prevent short circuits while batteries are being charged, tested, or handled. Hydrogen gas, which is accumulated while charging, is highly explosive and a spark from a shorted circuit could easily ignite the gas, causing serious damage to personnel and equipment.

Extreme caution should be exercised when installing and removing aircraft batteries. The nature of battery construction is such that the batteries are heavy for their size and are somewhat awkward to handle. These characteristics dictate the importance of using proper safety precautions. The information that has just been given, pointing out the danger of battery acid and gassing, due to charging, holds true for aircraft maintenance. There is the possibility of acid causing damage to equipment or injury to personnel and the danger of an explosion that may be caused from the gas that is produced as the aircraft generator charges the battery. Follow the prescribed safety precautions in working with batteries.

NOTE: Safety precautions applicable to handling and using nickel-cadmium and silver-zinc batteries are covered in chapter 6 of this course.

SELENIUM RECTIFIERS

When selenium rectifiers burn out, fumes of selenium dioxide are liberated, causing an overpowering stench. The fumes are poisonous and should not be breathed. If a rectifier burns out, deenergize the equipment immediately and ventilate the compartment. Allow the damaged rectifier to cool before attempting any repairs. If possible, move the equipment out of doors. Do not touch or handle the defective rectifier while it is hot since a skin burn might result through which some of the selenium compound could be absorbed.

LIQUID OXYGEN

Many naval aircraft are equipped with liquid oxygen systems. As an AE, you may be called upon to work in and around these systems. Liquid oxygen is very dangerous; therefore, applicable safety precautions must be rigidly observed.

The main dangers of liquid oxygen are the extremely low temperature of the liquid, its expansion ratio, and the supporting of violent combustion. The liquid is nontoxic, but will freeze (burn) the skin severely upon contact.

Extreme caution should be taken not to touch other implements containing liquid oxygen, unless gloves are worn. Without gloves, the skin will immediately stick to the metal surfaces.

A greater danger than freezing is the combustion-supporting potential of oxygen. When liquid oxygen is used, it is possible to build up high concentrations of oxygen quickly. Many materials such as cloth, wood, grease, oil, paint, or tar burn violently when saturated with oxygen, provided an ignition source is supplied. A static electric discharge or spark can serve as an igniter. Once an oxygen fire is started it is virtually impossible to extinguish it until the oxygen supply is cut off.

An added danger exists if a combustible material is saturated with oxygen at low temperatures. Many materials, especially hydrocarbons, tar, etc., will burn with explosive violence when so saturated and then subjected to very mild shock or impact.

Extreme care must be taken not to splash or spill liquid oxygen onto clothing. Mixed with cloth, an ideal and deadly situation for a fire exists—a fire that cannot be extinguished.

Liquid oxygen by itself will not burn, but mixing with the smallest amount of nearly any material will cause the liquid to boil and splash violently, and combustion is possible. If splashed out of a container, it will scatter widely upon contact with the ground.

LIQUID NITROGEN

Some of the more sophisticated electronic systems require the use of liquid nitrogen in their designed operation. Modern naval aircraft such as the F-8E employ liquid nitrogen tanks. As an Aviation Electrician's Mate, you may be called upon to work in and around these systems. It is paramount that all safety precautions be observed. The general safety precautions which apply to liquid oxygen also apply to liquid nitrogen. Liquid nitrogen should be treated just as liquid oxygen except that liquid nitrogen is not flammable. The greatest dangers of liquid nitrogen are severe burns.

The boiling point of any substance is the temperature at which the liquid turns to gas. At atmospheric pressure, the boiling point of liquid nitrogen is -321° F and liquid oxygen is -297° F. You can readily see that a great amount of heat must be removed from the air in order to liquefy it. A temperature of -321° F may be hard to imagine; therefore, it behooves maintenance personnel to be aware of the dangers while working on equipment near liquid nitrogen. When handling parts or equipment which have been cooled by liquid nitrogen, alway wear gloves. When handling liquid nitrogen, always wear goggles or a face shield, apron, and gloves. If liquid nitrogen is spilled on clothing, the clothing should be removed immediately. If the body should come in contact with liquid nitrogen, seek medical treatment immediately.

VOLATILE LIQUIDS

Volatile liquids, such as insulating varnish, lacquer, turpentine, and kerosene, are dangerous when used near electrical equipment which is operating because of the danger of igniting the fumes by sparks. When these liquids are used in compartments containing nonoperating equipment, be sure that there is sufficient ventilation to avoid an accumulation of fumes and that all fumes are cleared before the equipment is energized.

Neither alcohol nor gasoline should ever be used for cleaning. Use the approved cleaning agent, Dry Cleaning Solvent, Federal Specification P-S-661B.

The fire hazards encountered in the handling of hydrocarbon products (all present-day aviation fuels are hydrocarbons) are related to the flashpoint. Products which give off flammable vapors at or below 80° F, such as gasoline, solvents, and most crude oils, are the most hazardous of all petroleum products to handle. Certain petroleum products may be slightly less hazardous to handle, such as kerosene, light and heavy fuels, and lubricating oils which have a flashpoint above 80° F.

The vapor of petroleum, gasoline, and other petroleum products cause drowsiness when inhaled. Petroleum vapors in a concentration of 0.1 percent by volume may cause a slight vertigo (dizziness) at the end of 6 minutes; 0.1 percent can sometimes cause vertigo to the extent of inability to walk straight in 4 minutes. Longer exposure and/or greater concentration may cause unconsciousness or death. The first symptoms of exposure to toxic (poisonous) vapors are headaches, nausea, and dizziness. If such symptoms are noted, they

should be taken as warning of the presence of dangerous amounts of vapors in the air. Recovery from these early symptoms is usually prompt after removal to fresh air. However, if men are overcome by vapors, they should receive immediate medical attention. First aid consists of the prevention of chilling and of the application of artificial respiration if breathing has stopped.

The toxicity of heavy concentrations of vapors from gasoline or other fuel is increased if it contains tetraethyllead, added for antiknock purposes. This lead compound may be inhaled with the fumes or may enter the body through the mouth or by absorption through the skin, and is very poisonous.

Gasoline may cause skin irritations if allowed to remain in contact with the skin, particularly under soaked clothing or gloves. Clothing or shoes through which gasoline has soaked should be removed at once. Gasoline should be washed from the skin with soap and water. Repeated contact with gasoline removes the protective oils from the skin and causes drying, roughening, chapping, and cracking, and in some cases infections of the skin which may become serious.

If a person swallows gasoline, first aid should be given immediately. Giving the victim a large quantity of warm, salty water to drink in order to induce vomiting is an effective aid. Medical attention should be secured immediately.

JP-4 fuel, although it has some characteristics of gasoline, is by no means the same substance. Due to some of the different characteristics, such as lower vapor pressure and high aromatic (having compounds added to increase the performance number) content, this fuel must be handled very carefully.

JP-5 is a kerosene type fuel. It has a vapor pressure close to 0 psi. Since it has a lower tendency to vaporize than the more volatile grades, the vapor air mixture in tanks or containers above its liquid surface is too lean to be ignited until the surface of the liquid reaches a temperature of about 140° F. This fuel must also be handled with extreme care.

Precautions must be taken to prevent personnel from breathing fumes and to prevent the fuel from coming in contact with the skin especially if the skin has abrasions, pimples, or sores.

TEFLON WIRE PRECAUTIONS

Teflon is the proprietary name for polytetrafluoroethylene, a synthetic resin with exceptional characteristics for many applications. It is particularly useful as resistant seals and diaphragms, as insulation in electrical and electronic equipment, and as a dry lubricant applied usually as a film or an impregnate. It is inert, withstanding attack by chemicals, and is relatively unaffected by fairly high temperatures. Its electrical properties (high dielectric strength, widely stable dielectric constant, good dissipation factor, thermal stability, and resistance to moisture absorption) make it almost an ideal insulation. Used as a lubricant, it has the lowest coefficient of friction established for any solid material.

Since such a material is obviously desirable for many applications, it is unfortunate that there exists a widespread misconception concerning health hazards alleged to be associated with its use. The probable origin of this misconception is the fact that Teflon starts to decompose at about 400° F. However, the rate of decomposition is so slow and the total quantity of decomposition is so small that they cannot be determined by existing chemical techniques. With ventilation normally required for the processing of organic materials such as paints, plastics, and solvents, no adverse physiological effects are produced. Breathing fumes in areas inadequately ventilated, or smoking cigarettes or tobacco upon which Teflon powder or chips have been permitted to accumulate can, and have produced influenzalike symptoms which usually appear 2 to 6 hours after exposure and disappear within 24 to 36 hours. However, no health hazard exists with Teflon when it is properly handled under normal temperature and circumstances.

The following information may be used as a general guide for personnel handling, machining, or heating Teflon.

1. During machining of Teflon, a dust may be generated. Use local mechanical ventilation to control this dust. The use of coolant is also recommended because it permits higher cutting or grinding rates and simultaneously keeps the dust concentration to a low level.

2. If Teflon resins are heated for extended periods in the 400° F to 600° F range, minute quantities of decomposed matter are produced. Therefore, adequate mechanical ventilation

should be provided when working with Teflon at temperatures greater than 400° F.

3. Smoking should be prohibited in areas where Teflon is being fabricated in order to minimize the possibility of contaminating the pipe or cigarette with Teflon dust.

Additional information on the properties, handling, and medical evaluation of Teflon may be found in the Digest of U. S. Naval Aviation Electronics (NavWeps 08-1-503), Vol. 23, No. 3, of September 1963.

FIRST AID FOR ELECTRICAL SHOCK

Electric shock is a jarring, shaking sensation resulting from contact with electric circuits or from the effects of lightning. The victim usually feels that he has received a sudden blow; if the voltage and resulting current is sufficiently high, the victim may become unconscious. Severe burns may appear on the skin at the place of contact; muscular spasm may occur, causing the victim to clasp the apparatus or wire which caused the shock and be unable to turn it loose.

The following procedure is recommended for rescue and care of shock victims:

1. Remove the victim from electrical contact at once, but do not endanger yourself. This can be accomplished by: (1) Throwing the switch if it is nearby; (2) cutting the cable or wires to the apparatus, using an ax with a wooden handle while taking care to protect your eyes from the flash when the wires are severed; (3) using a dry stick, rope, belt, coat, blanket, or any other nonconductor of electricity, to drag or push the victim to safety.
2. Determine whether the victim is breathing. Keep him lying down in a comfortable position and loosen the clothing about his neck, chest, and abdomen so that he can breath freely. Protect him from exposure to cold, and watch him carefully.
3. Keep him from moving about. In this condition, the heart is very weak, and any sudden muscular effort or activity on the part of the patient may result in heart failure.
4. Do not give stimulants or opiates. Send for a medical officer at once and do not leave the patient until he has adequate medical care.
5. If the victim is not breathing, it will be necessary to apply artificial respiration without delay, even though he may appear to be lifeless.

For complete coverage on administering artificial respiration and treating burns, refer to Standard First Aid Training Course, NavPers 10081-A.

SAFETY PRECAUTIONS IN USING TOOLS

As a general precaution, be sure that all tools used conform to Navy standards as to quality and type, and use them only for the purposes for which they were intended. All tools in active use should be maintained in good repair, and all damaged or nonworking tools should be turned in.

Use only straight, undamaged, and properly sharpened drills. Tighten the drill securely in the chuck, using the key provided; never with wrenches or pliers. It is important that the drill be set straight and true in the chuck. The work should be firmly clamped and, if of metal, a center punch should be used to score the material before the drilling operation is started.

When using a portable power drill, grasp it firmly during the operation to prevent it from bucking or breaking loose, thereby causing injury to yourself or damage to the tool.

Care should be taken in selecting the correct type of pliers, side cutters, or diagonal cutters. Pliers or cutters should not be used on nuts or pipe fittings. When cutting short pieces, take care that they do not fly and cause injury. The fingers should not be wrapped around the handle of a tool in such a way that they can be pinched or jammed if the tool slips from the work. The use of extensions on the tool handle to increase leverage is prohibited.

In selecting a screwdriver for electrical work, be sure that it has a nonconducting handle. The screwdriver should not be used as a substitute for a punch or a chisel, and care should be taken that one is selected of the proper size to fit the screw. The point of the screwdriver should be kept in proper shape with a file or a grinding wheel.

Use wrenches only if they are in good condition and are right for the job. Never use a wrench as a hammer and do not put an extension on the handle. An adjustable wrench should be faced so that the movable jaw is located forward in the direction in which the handle is to be turned. When working in a confined space, the worker should take care that the grip he uses will not endanger him.

When using a fuse puller, make certain that it is the proper type and size for the particular fuse being pulled.

POWER TOOLS

In your work as an Aviation Electrician's Mate, you will most likely be required to use a few pieces of shop machinery, such as a power grinder or drill press. In addition to the general precautions on the use of tools, there are a few other precautions which should be observed when working with machinery. The most important ones are:

1. Never operate a machine with a guard or cover removed.
2. Never operate mechanical or powered equipment unless you are thoroughly familiar with the controls. When in doubt, consult the appropriate instruction or ask someone who knows.
3. Always make sure that everyone is clear before starting or operating mechanical equipment.
4. Never try to clear jammed machinery without first cutting off the source of power.
5. When hoisting heavy machinery (or equipment) by a chain fall, always keep everyone clear, and guide the hoist with lines attached to the equipment.
6. Never plug in electric machinery without insuring that the source voltage is the same as that called for on the nameplate of the machine.

PORTABLE POWER TOOLS

All portable power tools should be carefully inspected before being used to see that they are clean, well-oiled, and in a proper state of repair. The switches should operate normally, and the cords should be clean and free of defects. The casings of all electrically driven tools should be grounded. Sparking portable electric tools should not be used in any place where flammable vapors, gases, liquids, or exposed explosives are present.

Be sure that power cords do not come in contact with sharp objects. The cords should not be allowed to kink, nor be left where they might be run over. They should not be allowed to come in contact with oil, grease, hot surfaces, or chemicals; and when damaged, should be replaced instead of being patched with tape. When unplugging power tools from receptacles, grasp the plug, not the cord.

CHAPTER 3

ELEMENTARY PHYSICS

To the technician who must maintain the electrical equipment necessary to the operation of the Navy's aircraft, a knowledge of the basic principles of physics is extremely useful. The great value of a knowledge of physics lies in the fact that no matter how complex a machine or equipment is, its action can be satisfactorily explained as an application of basic physical principles.

The division between physics and other sciences cannot be well defined, because physics is the basic science that deals with motion, force, and energy as shown in the laws of mechanics, electricity, magnetism, sound, heat, and light. The physicist studies the phenomena which arise because matter moves, exerts force, and possesses energy. Principles of physics underlie all other sciences. In other words, physics is the science that deals with the phenomena associated with matter, motion, force, and energy, and the laws governing these phenomena.

STRUCTURE OF MATTER

Some basic facts concerning the structure of matter are presented in Basic Electricity, NavPers 10086-A, and in Basic Electronics, NavPers 10087-A (in connection with the study of transistors). The following paragraphs contain some review, but you should reread the material in the basic courses before continuing with the present discussion.

ATOMS

All matter is composed of atoms. The word "atom" comes from the Greek word "atomos," which means "indivisible." This meaning does not describe the atom in the light of present-day knowledge; we know now that atoms are composed of still smaller subatomic particles. These smaller particles can be split off the atom singly or in groups. The most recent and most spectacular method of splitting the atom is the process of nuclear fission, which takes place when an atomic bomb is exploded.

The ELECTRON, the PROTON, and the NEUTRON are the principal parts of the atom. Other subatomic particles have been discovered, but their functions are less important in electrical phenomena. Subatomic particles are arranged in the same general pattern in all atoms. Each atom has neutrons and protons closely packed together in its nucleus (core). The electrons can be considered as particles which revolve around the nucleus, just as the earth and other planets revolve around the sun.

A model of the atom, resembling a miniature solar system, was first constructed in 1913 by Niels Bohr, a Danish physicist. (See fig. 3-1.) The electrons and nucleus are so small that most of the volume of the atom is empty space.

The mass of a proton is nearly equal to the mass of a neutron and is about 1,840 times as great as the mass of an electron; therefore, practically all the mass of an atom is concentrated in its nucleus.

The hydrogen atom is the sole exception to the rule that all atoms are composed of three kinds of particles. The nucleus of a hydrogen atom is a single proton around which a single electron revolves. Figure 3-2 shows a hydrogen atom. Because of the extremely simple construction of its atom, hydrogen is the lightest substance known.

Although the weight of an atom is almost wholly concentrated in its nucleus, the nucleus of the atom has very little to do with the chemical nature of the element. The chemical characteristics are determined only by the number of electrons in the atom.

NOTE: The word "element" is used by chemists and physicists to signify any one of

approximately 100 substances which comprise the basic material of all matter. Two or more elements may combine chemically to form a compound; any combination which does not result in a chemical reaction between the different elements is called a mixture.

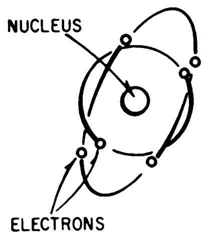


Figure 3-1.—Bohr model of the atom.

Although all the atoms of any particular element have the same atomic number—that is, the same number of protons—certain elements can exist in different forms, called **ISOTOPES**, which have the same chemical properties but have different atomic weights. An example of an element with multiple isotopes is uranium. Several different isotopes of uranium have been identified, but some have a very short life; for instance, ${}_{92}U^{227}$ has a half-life of only 1.3 minutes and the half-life of ${}_{92}U^{228}$ is only 9.3 minutes. (Half-life is defined as the period of time required for one-half of a sample of the element to change, by spontaneous radioactive decay, into a different element.) On the other hand, ${}_{92}U^{234}$, ${}_{92}U^{235}$, and ${}_{92}U^{238}$ have half-lives from 2.35×10^5 to 4.5×10^9 years. All uranium isotopes are so alike chemically that it is impossible to separate them using chemical means, and therefore physical methods of separation have been developed. All isotopes of uranium have the atomic number (Z number) 92. This explains the subscript 92 just ahead of the symbol U in the examples of isotopes given above. The Z number indicates how many protons (and therefore how many electrons) there are in an atom of the element. The superscript in a symbol such as ${}_{92}U^{235}$ indicates the atomic mass of the isotope; it is the sum of protons and neutrons in the nucleus.

The number of neutrons in each uranium isotope is found by subtracting 92 from the mass number. Thus, ${}_{92}U^{234}$ has 234 - 92 or 142 neutrons, and ${}_{92}U^{238}$ has 238 - 92 or 146 neutrons. Most chemical elements, even though "pure" by chemical standards, are found to be mixtures of isotopic forms which can be separated by physical methods, such as the use of the mass spectrograph. The Z number is frequently omitted when writing isotopic symbols, but the mass number is usually expressed so that the specific isotope is clearly indicated.

Nucleonics

The study of the nucleus of the atom, known as nucleonics, is the subject of much modern investigation. For the present you can think of the nucleus as being made up of protons and neutrons closely packed together. Experiments on nuclei usually involve bombardments in which various kinds of nuclear particles are shot into the nuclei of other atoms. Alpha particles (the nuclei of helium atoms), neutrons, and deuterons (the nuclei of heavy hydrogen) are the "bullets" used in these experiments. The linear accelerator, the cyclotron, the betatron, and the synchrotron are devices used to produce and accelerate these atomic bullets, which bombard the nuclei under investigation.

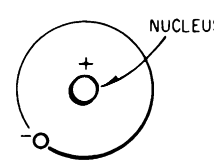


Figure 3-2.—Hydrogen atom.

The number of protons of the bombarded nucleus is sometimes altered by the bombardment. Because the only difference between elements is the number of their protons, electrons, and neutrons, one element can be changed or transmuted into another element by nuclear bombardment. When this change occurs, energy is usually released. Transmutation—the changing of one element into a different element—is the process that the alchemists of the middle ages dreamed about and sought after. In fact, it was this dream which gave impetus to the study of chemistry. The scientists in those days

thought that the way to transmute substances was by chemical reaction rather than by physical bombardment.

Electron Shells

The number and location of electrons in the atoms of an element determine the characteristics of that element. These electrons are arranged around the nucleus in successive groups or electron shells of rotation. Each of these shells is limited to a certain number of electrons. The first or inner shell can contain no more than 2 electrons. The second shell can contain no more than 8 electrons. The third shell can contain no more than 18 electrons. Designating the number of a shell in general as n, the maximum number of electrons in that shell is given by the expression $2n^2$.

An INERT ELEMENT—that is, an element which does not combine chemically with any other element—is a substance in which the outer electron shell of each atom is completely filled.

In an element that is not chemically inert, electrons are missing from the outer shell. An atom whose outer shell needs only 1 or 2 electrons (to be completely filled) can accept electrons from another element which has 1 or 2 "extras."

The concept of "extra" electrons arises from the basic fact that all atoms have a tendency toward completion (filling) of the outer shell. An atom whose outer shell has only 1 or 2 electrons would have to collect 6 or 7 additional ones (no easy task, from an energy standpoint) in order to have the required 8 for a full shell. A much easier way to achieve the same objective is to give up the 1 or 2 electrons in the outer shell and let the full shell next to it serve as the new outer shell. An element such as sodium, for example, has an extra electron; it would like to lose the single electron in its third shell, because its full second shell would then become the outer shell.

An example of a typical chemical reaction is found in the combination of sodium and chlorine to form the compound $NaCl$, which is common table salt. Sodium, with 11 electrons, has 1 extra; chlorine, with 17 electrons, needs only 1 more to complete its outer shell. When the atom of sodium loses its extra electron to chlorine, it becomes positively charged because it has lost 1 unit of negative charge. The chlorine atom, having gained 1 electron in the exchange, becomes negatively charged. The 2 IONS (charged atoms) thus formed stick together, since opposite charges attract.

MOLECULES

As indicated previously, elements may be mixed without necessarily undergoing any chemical change. For example, if finely powdered iron and sulfur are stirred and shaken together, the result is a mixture. Even if it were possible to grind this mixture to atom-size particles, the iron atoms and the sulfur atoms would remain distinct from each other.

Under certain conditions, however, two or more elements can be brought together in such a way that they unite chemically to form a compound. The resulting substance may differ widely from any of its component elements. For example, drinking water is formed by the chemical union of two gases, hydrogen and oxygen; table salt is compounded from chlorine (a gas) and sodium (a metal).

Whenever a compound is produced, two or more atoms of the combining elements join chemically to form the MOLECULE that is typical of the compound. The molecule is the smallest unit that shares the distinguishing characteristics of a compound.

ELEMENTS

All material is made up of one or more elements. These are substances that cannot be broken down into other and simpler substances by any chemical means. Ninety-two elements are found in nature, some of them in very small amounts. The remaining elements, of the 100 (approximately) mentioned before, are manmade.

Iron, mercury, and oxygen—existing at normal temperatures as a solid, a liquid, and a gas respectively—are typical elements. By heating, a solid element can be changed to a liquid and even to a gas. By cooling, a gaseous element can be changed to a liquid and even to a solid.

Hydrogen is the lightest element. Experiments have demonstrated that the oxygen atom is almost exactly 16 times as heavy as the hydrogen atom. Chemists express this truth by saying that oxygen has an atomic weight of 16. Continued experimentation has determined the atomic weights of the remaining elements.

Table 3-1 is a standard table of the elements. The atomic weight of each element appears below its name. The vertical columns represent family groups. All members—from lightest to heaviest—of a family behave like one another in forming (or in refusing to form) chemical compounds with other families.

MOLECULAR ACTIVITY

Normally, the molecules of any substance are in constant rotational and/or vibratory motion. In solids this motion is greatly restricted because of the rigidity of crystalline structures. In liquids the molecular motion is much less restricted, and in gases the motion is assumed to be entirely random. That is, the molecules are free to move in any direction and are in almost constant collision, both among themselves and against the walls of the container.

GASES

The moving particles of a gas possess energy of motion, or kinetic energy, the total of which is equivalent to the quantity of HEAT contained in the gas. When heat is added, the total kinetic energy is increased. When the gas is cooled, the thermal agitation is diminished and the molecular velocities are lowered.

The molecules do not all have the same velocity, not even in the same gas, but display a wide range of individual velocities. The TEMPERATURE of the gas, according to the kinetic theory, is determined by the average energy of the molecular motions. PRESSURE is accounted for by considering it as resulting from the bombardment of the walls of the container by the rapidly moving molecules. The particles are considered as approximating the ideal condition of perfect elasticity, so that they rebound from the walls with essentially the same velocities with which they strike them.

In accordance with the kinetic theory, if the heat energy of a given gas sample could be reduced progressively, a temperature would be reached at which the motions of the molecules would cease entirely. If known with accuracy, this temperature could then be taken as a natural reference, or a true absolute zero value. This value, which is usually expressed in terms of the centigrade scale, represents one of the fundamental constants of physics. It was established experimentally during a series of tests made with hydrogen.

Absolute Zero

Since any change in the temperature of a gas causes a corresponding change in the pressure, it was necessary to consider temperature, pressure, and volume together. The hydrogen was enclosed in a cylinder containing a movable piston so that the volume could be adjusted to maintain the initial pressure. The experiment was started with the gas at a temperature of 0° C.

It was found that when the gas was cooled enough to drop the temperature by 1° C, the volume had to be decreased by moving the piston in order to keep the sample at the same pressure. The new gas volume was then equal to 272/273 the volume at 0° C. As the temperature was lowered further, the volume (for constant pressure) decreased by an amount equal to 1/273 the initial volume for each decrease of 1° C.

When the volume was kept constant (by keeping the piston unchanged in position), it was found that the pressure varied at the same rate. That is, it decreased by an amount equal to 1/273 the pressure at 0° C for each change in the temperature of 1 degree.

The same rates of change of volume and pressure were found to be present in all gases and not in hydrogen alone; in addition, they were uniform over a wide range of temperature. All these facts led to the theory that if any gas were cooled to -273°C (actually -273.16), with the pressure kept constant, the volume would shrink to zero. However, all known gases change to the liquid state before this temperature is reached and the volume-temperature coefficient for liquids is quite different from that of gases. Also, if the volume were maintained at the initial value, the pressure would approach zero as the temperature approached this same value. It was then assumed that -273°C (approximately) represents the theoretical absolute zero point at which all molecular motion ceases and no more heat remains in the substance to be extracted.

The existence of absolute zero cannot be determined directly by observing the volume of gas cooled to -273°C, since all gases are converted to the liquid state before this temperature is reached. In many experiments, however, this condition has been approached closely, the actual temperature reached being a small fraction of a degree above the theoretical zero value.

Table 3-1.—Periodic chart of the elements.

Series	Period	Zero Group	Group I	Group II	Group III	Group IV	Group V	Group VI	Group VII	Group VIII		
0												
1			Hydrogen H=1.0078 No. 1									
2	1	Helium He=4.002 No. 2	Lithium Li=6.940 No. 3	Beryllium Be=9.02 No. 4	Boron B=10.82 No. 5	Carbon C=12.00 No. 6	Nitrogen N=14.008 No. 7	Oxygen O=16.000 No. 8	Fluorine F =19.00 No. 9			
3	2	Neon Ne=20.183 No. 10	Sodium Na=22.997 No. 11	Magnesium Mg=24.32 No. 12	Aluminum Al=26.06 No. 13	Silicon Si=28.06 No. 14	Phosphorus P=31.02 No. 15	Sulfur S=32.06 No. 16	Chlorine Cl=35.457 No. 17			
4	3	Argon A=39.944 No. 18	Potassium K=39.10 No. 19	Calcium Ca=40.08 No. 20	Scandium Sc=45.10 No. 21	Titanium Ti=47.90 No. 22	Vanadium V=50.95 No. 23	Chromium Cr=52.01 No. 24	Manganese Mn=54.93 No. 25	Iron Fe=55.84 No. 26	Cobalt Co=58.94 No. 27	Nickel Ni=58.69 No. 28
5			Copper Cu=63.57 No. 29	Zinc Zn=65.38 No. 30	Gallium Ga=69.72 No. 31	Germanium Ge=72.60 No. 32	Arsenic As=74.93 No. 33	Selenium Se=79.2 No. 34	Bromine Br=79.916 No. 35			
6	4	Krypton Kr = 82.9 No. 36	Rubidium Rb=85.44 No. 37	Strontium Sr=87.63 No. 38	Yttrium Y=88.92 No. 39	Zirconium Zr=91.22 No. 40	Columbium Cb=93.3 No. 41	Molyb- denum Mo=96.0 No. 42	Masurium Ma=? No. 43	Ruthenium Ru=101.7 No. 44	Rhodium Rh=102.91 No. 45	Palladium Pd=106.7 No. 46
7			Silver Ag=107.880 No. 47	Cadmium Cd=112.41 No. 48	Indium In=114.8 No. 49	Tin Sn=118.70 No. 50	Antimony Sb=121.76 No. 51	Tellurium Te=127.5 No. 52	Iodine I=126.932 No. 53			
8	5	Xenon Xe=130.2 No. 54	Caesium Cs=132.81 No. 55	Barium Ba=137.36 No. 56	Lanthanum La=138.90 No. 57	Cerium Ce=140.13 No. 58						
9												
10	6					Hafnium Hf=178.6 No. 72	Tantalum Ta=181.4 No. 73	Tungsten W=184.0 No. 74	Rhenium Re=186.31 No. 75	Osmium Os=190.8 No. 76	Iridium Ir=193.1 No. 77	Platinum Pt=195.23 No. 78
11			Gold Au=197.2 No. 79	Mercury Hg=200.61 No. 80	Thallium Tl=204.39 No. 81	Lead Pb=207.22 No. 82	Bismuth Bi=209.00 No. 83	Polonium Po=209.99 No. 84	Alabamine Am=? No. 85			
12	7	Radon Rn=222 No. 86	Virginium Va=? No. 87	Radium Ra=225.97 No. 88	Actinium Ac=227.02 No. 89	Thorium Th=232.12 No. 90	Photo- Actinium Pa=231.03 No. 91	Uranium U=238.14 No. 92	Neptunium Np=? No. 93	Plutonium Pu=? No. 94	Americium Am=? No. 95	Curium Cm=? No. 96

Elements Nos. 59 through 71 are not classified in the table above.

Kelvin Scale

When temperatures are measured with respect to -273° C, they are said to be expressed in the absolute, or Kelvin, scale. Specific absolute temperatures are designated by the letter K. Thus, 0° C is equivalent to 273° K; 20° C equals 293° K, and 100° C equals 373° K.

In formulas, Kelvin temperatures in general are indicated by the letter T, thus:

$$T = C + 273$$

where T is the temperature in degrees Kelvin, and C is the centigrade reading. In all problems involving gas temperatures, values given in centigrade or Fahrenheit must be converted to the absolute scale.

Laws of Gases

The basic laws governing gases can be expressed in simple formulas stating the general relations of volume, pressure, and temperature. One of the most important of these principles concerns the relation of gas volume to pressure. It has been known since the seventeenth century and is associated with the name of Robert Boyle, an English scientist of that time who first announced it.

BOYLE'S LAW.—Boyle was among the first to study what he called the "springiness of air." He learned by direct measurement that if the temperature of an enclosed body of gas is kept constant, the volume is reduced to half the former value when the pressure is doubled. As the applied pressure decreases, the resulting gas volume increases; or in general, the product of the volume and pressure remains constant. Boyle formulated the general law which can stated as follows:

> When the temperature is held constant, the volume of any dry gas varies inversely with the applied pressure.

This can be expressed in equation form in two ways:

$$V_1 P_1 = V_2 P_2, \text{ or}$$

$$\frac{V_1}{V_2} = \frac{P_2}{P_1}$$

where V_1 and P_1 refer to the original volume and pressure, and V_2 and P_2 refer to the new volume and to the new pressure which causes it.

Gas pressure may be indicated in one of two ways—absolute pressure or gage pressure. If the pressure is expressed as being a certain number of units greater than the zero pressure of a complete vacuum, the measurement is called absolute pressure. This is the actual pressure exerted by the confined gas. Atmospheric pressure at sea level is approximately 14.7 pounds per square inch (psi), and this factor must be taken into consideration when measuring gas pressure.

When a pressure is expressed as the difference between its absolute value and that of the local atmospheric pressure, the measurement is called gage pressure. Gage pressure may be converted to absolute pressure by adding the local atmospheric pressure to the gage pressure. When the values are given in psi, the rule can be stated in this way: Absolute pressure equals gage pressure plus 14.7 psi.

In connection with volume and pressure, consider the following problems which involves Boyle's law. (NOTE: Boyle's law applies only with absolute pressure.) Nitrogen is confined in a container with a volume of 2 cubic feet. The gage pressure is 150 psi. If the gas is allowed to expand to a volume of 10 cubic feet with no change in temperature, what is the new value of gage pressure?

The gage reading must first be converted to absolute pressure by adding the atmospheric pressure, which is 14.7 psi, to the gage pressure. The resulting value, the original volume, and the new volume are then substituted in the formula:

$$V_1 P_1 = V_2 P_2$$

$$(2) \times (150 + 14.7) = (10) \times (P_2)$$

$$P_2 = \frac{(2) \times (164.7)}{10}$$

$$P_2 = 32.94 \text{ psi, absolute}$$

Converting absolute to gage pressure, 32.94 - 14.7 = 18.24 psi, gage pressure.

Various applications of Boyle's law are found in aircraft instruments that use varying degrees of volume or pressure.

CHARLES' LAW.—This law consists of two general statements which relate the temperature of a gas to (1) the volume with the pressure held

constant, and (2) the pressure with the volume constant. The principle is named in honor of a French physicist, whose studies provided much of the foundation for the modern kinetic theory of gases. Charles found that all gases expand and contract in direct proportion to the change in the absolute temperature, provided the pressure is held constant. Expressed in equation form, this part of the law is given by

$$V_1T_2 = V_2T_1, \text{ or}$$

$$\frac{V_1}{V_2} = \frac{T_1}{T_2}$$

where V_1 and V_2 refer to the original and final volumes; and T_1 and T_2 indicate the corresponding temperatures measured on the Kelvin scale.

Since the volume of a gas increases as the temperature rises, it is reasonable to expect that if a given mass of gas were heated, and yet confined in the same space, the pressure would increase. In the experiments described in a preceding section, it was found that the increase in pressure for any gas kept at constant volume was very nearly 1/273 of the pressure at 0° C for each increase of 1° C. Because of this fact, it is convenient to state this relationship in terms of absolute temperature. In equation form, this part of Charles' law becomes

$$P_1T_2 = P_2T_1, \text{ or}$$

$$\frac{P_1}{P_2} = \frac{T_1}{T_2}$$

In words, this states that with constant volume the absolute pressure of any gas varies directly with the absolute temperature.

The following problem illustrates Charles' law: An accumulator filled with nitrogen under a gage pressure of 2,000 psi, at a temperature of 25° C, is left in the sun. It heats to a temperature of 55° C. What is the new gage pressure?

The pressure and temperature data are converted into absolute values and substituted in the formula:

$$P_1T_2 = P_2T_1$$

$$(2{,}000 + 14.7) \times (55 + 273) = (P_2) \times (25 + 273)$$

$$P_2 = \frac{660{,}821.6}{298}$$

$$P_2 = 2{,}217.5 \text{ psi, absolute.}$$

Converting absolute to gage pressure,

$$2{,}217.5 - 14.7 = 2{,}202.8 \text{ psi, gage}$$

GENERAL GAS LAW.—The facts concerning gases discussed in the preceding sections are summed up and illustrated in figure 3-3. Boyle's law is expressed in (A) of the figure; while the effects of temperature changes on pressure and volume (Charles' law) are illustrated in (B) and (C), respectively.

By combining Boyle's and Charles' laws, a single expression can be derived which states

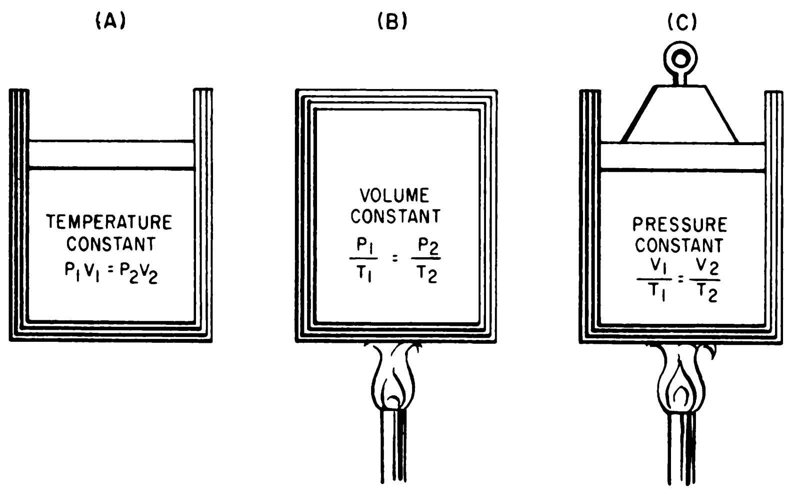


Figure 3-3.—The general gas law.

all the information contained in both. This expression is called the GENERAL GAS EQUATION, a very useful form of which is given by the following (NOTE: The capital P and T signify absolute pressure and temperature, respectively):

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

It can be seen by examination of figure 3-3 that the three equations it illustrates are special cases of the general equation. Thus, if the temperature remains constant, T_1 equals T_2 and both of these can be eliminated from the general formula, which then reduces to the form shown in (A). When the volume remains constant, V_1 equals V_2, thereby reducing the general equation to the form given in (B). Similarly, P_1 is equated to P_2 for constant pressure, and the equation then takes the form given in (C).

The general gas law applies with exactness only to "ideal" gases in which the molecules are assumed to be perfectly elastic. However, it describes the actual behavior of gases with sufficient accuracy for most practical purposes. In the form given above, the equation involves six variable quantities, five of which must be known in order to find the sixth. As an example of its use, consider the following problem in which it is required to find the gage pressure resulting from changes in both temperature and volume:

A certain gas has a volume of 4 cubic feet at a gage pressure of 150 psi. It is compressed to a volume of 2 cubic feet and heated from an initial temperature of 70° C to 300° C. What is the final gage pressure?

The pressure and temperature data are converted to absolute values; these are substituted in the general equation; and the resulting expression is solved for P_2:

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

$$\frac{(164.7) \times (4)}{(70 + 273)} = \frac{(P_2) \times (2)}{(300 + 273)}$$

$$P_2 = \frac{(164.7) \times (4) \times (573)}{(2) \times (343)}$$

$$P_2 = 550.3 \text{ psi, absolute}$$

Converting absolute to gage pressure,

$$550.3 - 14.7 = 535.6 \text{ psi, gage}$$

LIQUIDS

The fundamental characteristics of liquids are discussed in Basic Hydraulics, NavPers 16193. Chapters 1, 2, and 13 contain information that is basic to all applications of hydraulics. Some of the more important topics discussed in these chapters are the development of hydraulics, physical properties of liquids, relation of pressure and force in hydraulic systems, influence of atmospheric pressure on hydraulic systems, and fluids in motion.

Since this publication is generally available throughout the Navy, this information is not repeated in this chapter. Some of the equipment that the AE is required to operate and maintain utilizes hydraulic principles; therefore, it is recommended that you obtain this publication and become familiar with its contents, particularly chapters 1, 2, and 13.

The theory of hydraulics presented in Basic Hydraulics can be summarized by the following facts concerning liquids:

1. Liquids are shapeless, completely flexible, and flow readily into enclosures of any form.
2. Liquids are practically incompressible; and applied pressures are transmitted through them instantaneously, equally, and undiminished, to all points on the enclosing surfaces.
3. Hydraulic apparatus can be used to increase or decrease input forces, thus providing an action similar to that of mechanical advantage in mechanical systems.

Because of these properties, hydraulic servomechanisms have advantages as well as disadvantages and limitations, when compared with other kinds of systems. The fluidity of hydraulic liquid permits different parts of the hydraulic servo to be placed conveniently and at widely separated points if necessary. The application of pressure is uniform throughout the system and takes place with small losses. Hydraulic power units can transmit energy around corners and bends without the use of complicated gears and levers, and they operate without the slack and friction often present in mechanical linkages. The uniform action is without vibration, and the operation of the system remains largely unaffected by variations in the load value.

SOLIDS

The properties of a solid which are commonly listed are cohesion and adhesion, tensile strength, ductility, malleability, hardness, brittleness, and elasticity. Ductility is a measure of the ease with which the material can be drawn into a wire. Malleability refers to the ability of some materials to assume new shape when pounded. Hardness and brittleness are self-explanatory terms. The remaining properties mentioned above are discussed in more detail in the following paragraphs.

Cohesion and Adhesion

Cohesion is the molecular attraction between like particles throughout a body or the force that holds any substance or body together. Adhesion is the molecular attraction existing between surfaces of bodies in contact or the force which causes unlike materials to stick together.

Cohesion and adhesion are possessed by different materials in widely varying degree. In general, solid bodies are highly cohesive but only slightly adhesive. Fluids, on the other hand, are quite highly adhesive but only slightly cohesive. Generally, a material having one of these properties to a high degree will possess the other property to a relatively low degree.

Tensile Strength

The cohesion between the molecules of a solid explains the property called tensile strength. This is a measure of the resistance of a solid to being pulled apart. Steel possesses this property to a high degree, and is thus very useful in structural work. When a break does occur, the pieces of the solid cannot be stuck back together because merely pressing them together does not bring the molecules into close enough contact to restore the molecular force of cohesion. However, melting the edges of the break allows the molecules on both sides of the break to flow together, thus bringing them once again into the close contact required for cohesion.

Elasticity

If a substance will spring back to its original form after being deformed, it has the property of elasticity. This property is desirable in materials to be used as springs. Steel and bronze are examples of materials which exhibit this property.

Elasticity of compression is exhibited by all liquids, solids, and gases. The closeness of the molecules in solids and liquids makes them hard to compress, but gases are easily compressed because the molecules are farther apart.

DENSITY AND SPECIFIC GRAVITY

The density of a substance is its weight per unit volume, or

$$D = \frac{W}{V}$$

Because a cubic foot of water weighs 62.4 pounds, the density of water is 62.4 pounds per cubic foot. In the metric system the density of water is 1 gram per cubic centimeter.

The specific gravity (S.G.) of a substance is the ratio of the density of the substance to the density of water—

$$\text{S.G.} = \frac{\text{weight of substance}}{\text{weight of equal volume of water}}$$

Specific gravity is not expressed in units but as a pure number which tells how many times a substance is as heavy as water. For example, if a substance has a specific gravity of 4, one cubic foot of the substance weighs 62.4 times 4 or 249.6 pounds. In metric units, one cubic centimeter of a substance with a specific gravity of 4 weighs 1 times 4 or 4 grams. Note that in the metric system of units, the specific gravity of a substance has the same numerical value as its density. Because the density of water is 1 gram per cubic centimeter, a substance whose specific gravity is 4 has a density of 4 grams per cubic centimeter. Specific gravity and density are independent of the size of the sample under consideration, and depend only upon the composition of the substance. See table 3-2 for typical values of specific gravity for various substances.

Table 3-2.—Typical values of specific gravity.

Substance	Specific gravity
Aluminum	2.7
Brass	8.6
Copper	8.9
Ethyl alcohol	0.81
Gold	19.3
Ice	0.92
Iron	7.8
Lead	11.3
Mercury	13.6
Platinum	21.3
Silver	10.5
Steel	7.8
Water	1.00

Volume

Volume is the amount of space enclosed within the bounding surfaces of a body. To determine the volume of a regularly shaped body, three measurements of length are required—

$$\text{Volume} = \text{length} \times \text{width} \times \text{depth (height)}$$
$$V = lwh$$

Volume is said to have dimensions of length cubed because it is the product of three length measurements. The unit of volume is a cube having edges of unit length. (See fig. 3-4.)

A great deal of ingenuity often is needed to measure the volume of irregularly shaped bodies. Sometimes it is practical to divide a body into a series of regularly shaped parts and then apply the rule that the total volume is equal to the sum of the volumes of all individual parts. Figure 3-5 demonstrates another method of measuring the volume of small irregular bodies. The volume of water displaced by a body submerged in water is equal to the volume of the body.

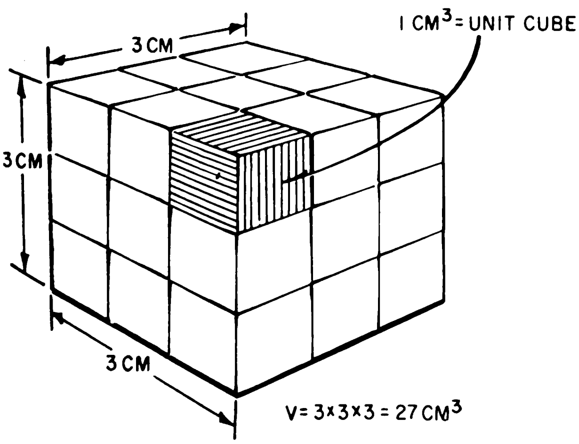


Figure 3-4.—Volume measurement.

The unit of volume most used in a cube with an edge of unit length. In the English system, volume is usually measured in cubic feet or cubic inches. (See table 3-3.) Thus the unit is a cube, 1 foot or 1 inch on each edge. In the metric system the cubic centimeter or cubic meter is used. Another unit commonly used in the metric system is the LITER. The liter is the volume of a cube 10 centimeters on each edge. The liter, therefore, contains 1,000 cubic centimeters.

Table 3-3.—English and metric units of volume.

1 cubic foot (cu ft) = 1,728 cubic inches (cu in.).
1 cubic yard (cu yd) = 27 cu ft.
1 gallon (gal) = 4 quarts (qt) = 231 cu in.
1 liter (1) = 1,000 cubic centimeters (cu cm).
1 cubic meter (cu m) = 1,000 liters
1 liter = 1.06 liquid quarts.

Relation to Temperature

Nearly all substances expand or increase in size when their temperature increases. Railroad tracks are laid with small gaps between the sections to prevent buckling when the temperature increases in summer. Concrete pavement has strips of soft material inserted at intervals to prevent buckling when the sun heats the roadway. A steel building or bridge is put together with red-hot rivets so that when the rivets cool they will shrink and the separate pieces will be pulled together very tightly.

As a substance is expanded by heat, the weight per unit volume decreases. This is because the weight of the substance remains the same while the volume is increased by the application of heat. Thus the density decreases with an increase in temperature.

HEAT

Heat may be produced in a number of ways. For example, when two sticks are rubbed

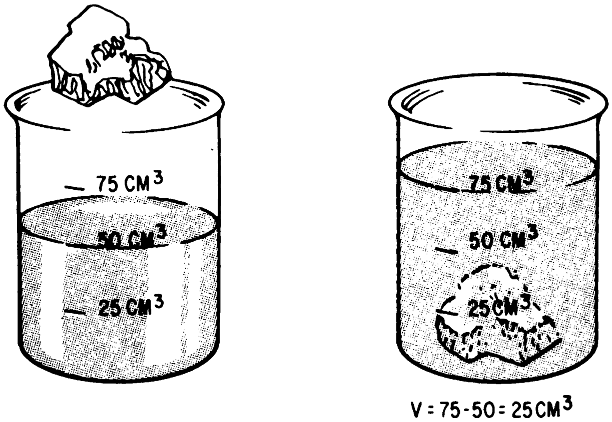


Figure 3-5.—Measuring volume of irregular object.

vigorously together, they become hot. When a piece of lead is struck a number of sharp blows or when a dull drill is used on a piece of metal, heat is produced. (See fig. 3-6.) According to modern theories, an increase in temperature means an increase in the average velocity of molecular motion.

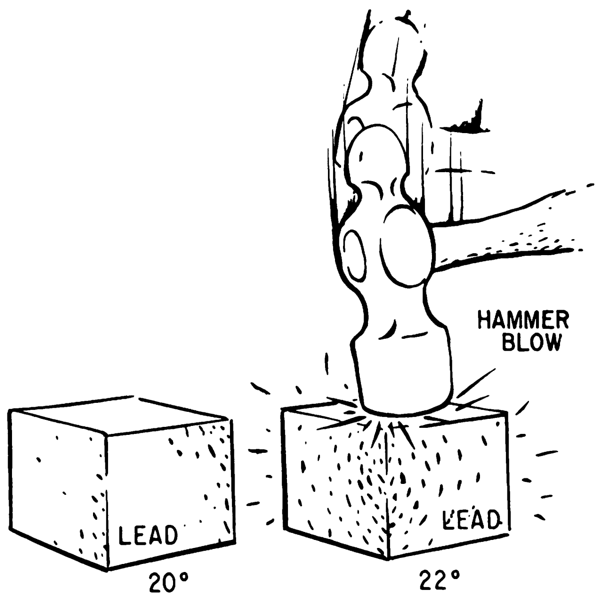


Figure 3-6.—Generation of heat.

In the three examples of heat production mentioned above, the friction resulting from the rubbing or pounding of hard substances against each other provided the method of increasing the molecular velocity. Many other physical methods, including electrical excitation, are used to induce heating.

METHODS OF TRANSFER

An important part of the study of heat is the problem of heat transfer. There are three methods by which heat is transferred from one location to another or from one substance to another. The names of these are conduction, convection, and radiation.

Conduction

You know from experience that the metal handle of a heated pot can burn your hand. A plastic or wood handle, however, remains relatively cool even though it is in direct contact with the pot. The metal transmits the heat more easily than the wood because it is a better conductor of heat. Different materials conduct heat at different rates. Some metals are much better conductors of heat than others. Aluminum and copper are used for pots because they conduct heat to the food very rapidly. Wood and plastics are used for handles because they do not conduct heat very well and therefore protect your hands from the heat.

Figure 3-7 shows an example of the different rates of conduction of various metals. Four rods of different metals have several wax rings

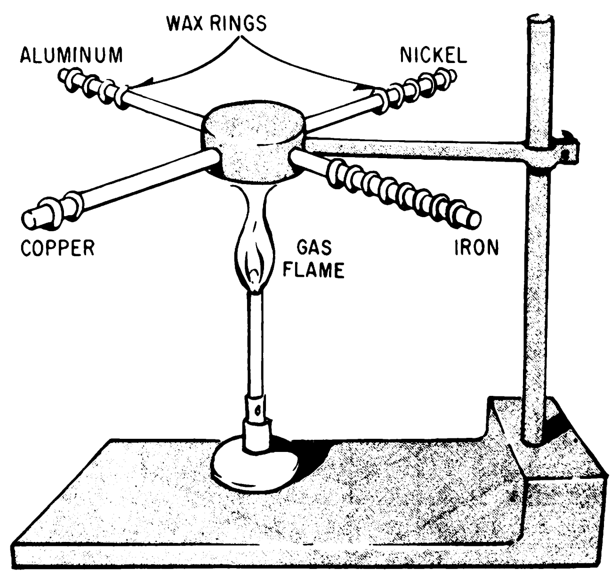


Figure 3-7.—Various metals conduct heat at different rates.

hanging on them. One flame is used to simultaneously heat one end of each rod. The rings drop off from the copper rod first, then from the aluminum rod, then from the nickel rod, and last from the iron rod. This example shows that among the four metals used, copper is the best conductor of heat and iron is the poorest.

Liquids are poorer conductors of heat than metals. Notice that the ice in the test tube shown in figure 3-8 is not melting rapidly even though the water at the top is boiling. The water conducts heat so poorly that not enough heat reaches the ice to melt it.

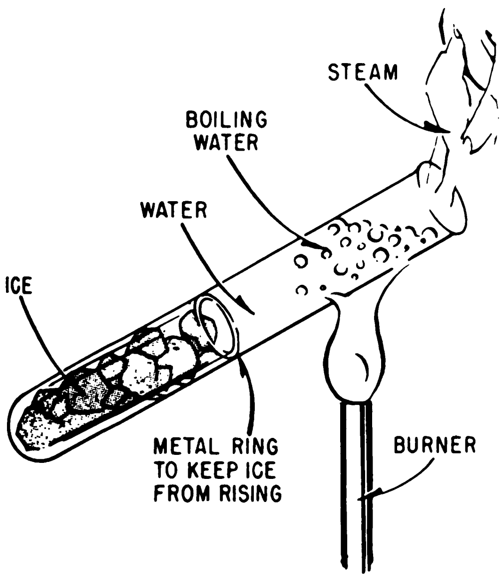


Figure 3-8.—Water is a poor conductor of heat.

Gases are even poorer conductors of heat than liquids. You can stand quite close to a stove without being burned because air is such a poor conductor. Since conduction is a process whereby the increase in molecular energy is passed along by actual contact, gases are poor conductors.

At the point of application of the heat source the molecules become violently agitated. These molecules strike the molecules next to them and cause them to agitate. This process continues until the heat energy is distributed evenly throughout the substance. Because molecules are farther apart in gases than in solids, the gases are much poorer conductors of heat.

Materials that are poor conductors are used to prevent the transfer of heat and are called heat insulators. A wooden handle on a pot or a soldering iron serves as a heat insulator. Certain materials such as finely spun glass and a mineral named asbestos are particularly poor heat conductors. These materials are therefore used for many types of insulation when there is a difference in ambient (surrounding) temperatures.

Convection

Convection is the process in which heat is transferred by movement of a heated fluid. For example, an electronic tube gets hotter and hotter until the air surrounding it begins to move. The motion of the air is upward. This upward motion of the heated air carries the heat away from the hot tube by convection. Transfer of heat by convection may be hastened by using a ventilating fan to move the air surrounding a hot object. The rate of cooling of a hot vacuum tube can be increased if it is provided with copper fins that conduct heat away from the hot tube. The fins provide large surfaces against which cool air can be blown. (See fig. 3-9.)

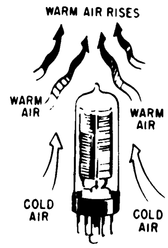


Figure 3-9.—Vacuum tube cooled by convection.

A convection process may take place in a liquid as well as in a gas. Figure 3-10 shows a transformer is an oil bath. The hot oil is less dense (has less weight per unit volume) and rises, while the cool oil falls, is heated, and rises in turn.

When the circulation of gas or liquid is not rapid enough to remove sufficient heat, fans or pumps are used to accelerate the motion of the cooling material. In some installations, pumps are used to circulate water or oil to help cool large equipment. In airborne installations electric fans and blowers are used to aid convection.

Radiation

Conduction and convection cannot wholly account for some of the phenomena that are

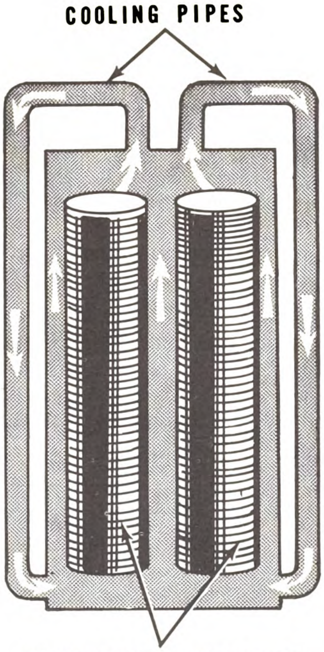


Figure 3-10.—Oil convection currents cool a transformer.

associated with heat transfer. For example, if you sit in front of an open fire, the heat that you feel on your face cannot come to you through convection because the air currents are moving toward the fire. It cannot come to you through conduction because the conductivity of the air is very small and the cooler currents of air moving toward the fire would more than overcome the transfer of heat outward. Therefore, there must be some way for heat to travel across space other than by conduction and convection.

The existence of another process of heat transfer is still more evident when the heat from the sun is considered. Since conduction and convection take place only through some medium such as a gas or a liquid, heat from the sun reaches the earth by another method. (Outer space is an almost perfect vacuum.) Radiation is the name given to this third method by which heat travels from one place to another.

The term radiation refers to the continual emission of energy from the surface of all bodies. This energy is known as radiant energy. It is in the form of electromagnetic waves and is identical in nature with light waves, radio waves, and X-rays, except for a difference in wavelength. These waves travel at the velocity of light and are transmitted through a vacuum more easily than through air because air absorbs some of them. Most forms of energy can be traced back to the energy of sunlight. Sunlight is a form of radiant heat energy which travels great distances through cold, empty space to reach the earth. These electromagnetic heat waves are absorbed when they come in contact with nontransparent bodies. The net result is that the motion of the molecules in the body is increased as indicated by an increase in the temperature of the body.

The differences between conduction, convection, and radiation may now be considered. First, although conduction and convection are extremely slow, radiation takes place with the speed of light. This fact is evident at the time of an eclipse of the sun when the shutting off of the heat from the sun takes place at the same time as the shutting off of the light. Second, radiant heat may pass through a medium without heating it. For example, the air inside a greenhouse may be much warmer than the glass through which the sun's rays pass. Third, although conducted or convected heat may travel in roundabout routes, radiant heat always travels in a straight line. For example, radiation can be cut off with a screen placed between the source of heat and the body to be protected.

ABSORPTION.—The sun, a fire, and an electric light bulb all radiate energy but a body need not glow to give off heat. A kettle of hot water or a hot soldering iron radiates heat. If the surface is polished or light in color, less heat is radiated. Bodies which do not reflect are good radiators and good absorbers, and bodies that reflect are poor radiators and poor absorbers. For this reason white clothing is worn in the summer season. A practical example of the control of loss of heat is the Thermos bottle. The flask itself is made of two walls of glass with a vacuum in between and with the walls silvered. The vacuum prevents the loss of heat by conduction and convection, and the silver coating prevents the loss of heat by radiation.

From the preceding paragraph, you can understand readily that the silver-colored bronze paint with which radiators used in heating systems are painted is used only for decoration and decreases the efficiency of the heat transfer. The most effective color to paint them is dull black. As dull black is the ideal absorber, it is also the best radiator.

HEAT MEASUREMENTS

Some confusion exists among trainees concerning the two basic types of measurements that are necessary in the study of heat. The measurement with which you are probably most familiar is thermometry, or temperature measurement. The second type is the measurement of quantity of heat; this is called calorimetry. Changes in heat quantity are measured by the effects they produce. Among these effects, one of the most obvious is temperature change. A change in heat quantity is often, though not always, accompanied by a change in temperature.

Calorimetry

A unit of heat quantity must be defined as the heat necessary to produce some agreed-on standard of change. There are three such units in common use, the British thermal unit (Btu), the gram-calorie (small calorie) and the kilogram-calorie (large calorie). One Btu is the quantity of heat necessary to raise the temperature of 1 pound of water 1° F. One gram-calorie is the quantity of heat necessary to raise 1 gram of water 1° C. One kilogram-calorie is the quantity of heat necessary to raise 1 kilogram of water 1° C. It is evident then that 1 kilogram-calorie equals 1,000 gram-calories. The gram-calorie or small calorie is much more widely used than the kilogram-calorie or large calorie. The large calorie is used in the relation to food energy. Throughout this discussion, unless otherwise stated, the term "calorie" means "gram-calorie." For purposes of conversion, 1 Btu equals 252 gram-calories or 0.252 kilogram-calories.

The terms "quantity of heat" and "temperature" are commonly misused. The distinction between them should be understood clearly. For example, suppose that two identical pans, containing different amounts of water of the same temperature, are placed over identical gas burner flames for the same length of time. At the end of that time, the smaller amount of water will have reached a higher temperature. Equal amounts of heat have been supplied but the increase in temperatures is not equal. As another example, suppose that the water in both pans is at the same temperature, say 80° F, and both are to be heated to the boiling point. It is obvious that more heat must be supplied to the larger amount of water. The temperature rise is the same for both pans, but the quantities of heat necessary are different.

MECHANICAL EQUIVALENT.—Mechanical energy is usually expressed in ergs, joules, or foot-pounds. Energy in the form of heat is expressed in calories or in Btu. In a precise experiment in which electric energy is converted into heat in a resistance wire immersed in water, the results show that 4.186 joules equals 1 calorie, or 778 foot-pounds equals 1 Btu. The following equation is used when converting from the English system to the metric system:

$$1 \text{ Btu} = 252 \text{ calories}$$

SPECIFIC HEAT.—One important way in which substances differ from one another is that they require different quantities of heat to produce the same temperature change in a given mass of the substance. The specific heat capacity of a substance is the quantity of heat needed, per unit mass, to increase the temperature 1° C. The specific heat of a substance is the ratio of its specific heat capacity to the specific heat capacity of water. Specific heat is expressed as a number which, because it is a ratio, has no units and applies to both the English and the metric systems.

It is fortunate that water has a high specific heat capacity. The larger bodies of water on the earth keep the air and solid matter on or near the surface of the earth at a fairly constant temperature. A great quantity of heat is required to change the temperature of a large lake or river. Therefore, when the temperature falls below that of such bodies of water they give off large quantities of heat. This process keeps the atmospheric temperature at the surface of the earth from changing very rapidly.

The specific heats of some common materials are given in table 3-4.

Table 3-4.—Specific heat values.

Material	Specific heat
Mercury	0.033
Copper	0.095
Iron and steel	0.113
Glass	0.200
Alcohol	0.500
Water	1.000

Two simple problems involving the use of specific heat follow:

1. How many Btu are required to heat a 4-ounce soldering iron from 70° F to 500° F? Use the specific heat of copper from table 3-4.

Btu = (specific heat) x (weight in pounds) x (change in temperature)

$$\text{Btu} = 0.095 \times \frac{4 \text{ oz}}{16 \text{ oz}} \times (500 - 70) = 10.21$$

2. How many calories are required to heat 15 grams of mercury from 20° C to 95° C?

cal = (specific heat) x (grams) x (change in temperature)

$$\text{cal} = 0.033 \times 15 \times (95 - 20) = 37.125$$

Compare this answer with the amount of heat required to raise 15 grams of water to the same temperature. (See fig. 3-11.)

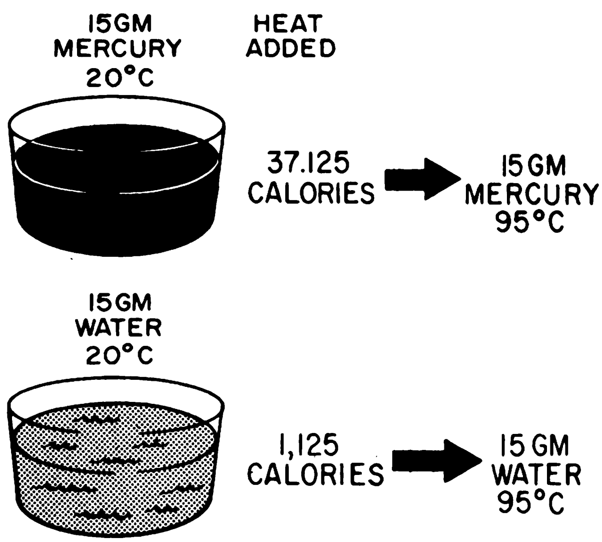


Figure 3-11.—Different amounts of heat required to produce the same change in temperature.

COMBUSTION.—A common method used to produce heat energy is the burning process. Burning is a chemical process in which the fuel unites with oxygen, and a flame is usually produced. The amount of heat liberated per unit mass or per unit volume during complete burning is known as the heat of combustion of a substance. By experiment, scientists have found that each fuel produces a given amount of heat per unit quantity burned. A list of the heats of combustion of some substances is given in table 3-5.

Table 3-5.—Heats of combustion.

Substance	Heat liberated
Coal gas	600 Btu per cu ft
Natural gas	1,000 to 2,500 Btu per cu ft
Coal	11,000 to 14,000 Btu per lb
Ethyl alcohol	14,000 Btu per lb
Fuel oil	20,000 Btu per lb

Chemical change, of which combustion is an example, is one of the two major types of change (other than nuclear change) which may occur in a substance. The other type is physical change, or change of state, in which the physical form and appearance of a substance change while its chemical composition remains the same. The term "change of state" has its origin in the fact that matter exists in three "states" (conditions): solid, liquid, and gas. Among the physical changes to be discussed in the following paragraphs are fusion (melting), vaporization, and boiling.

CHANGE OF STATE.—As an example of a change of state which absorbs heat, notice that a thermometer placed in melting snow behaves in a seemingly strange manner. (See fig. 3-12.)

The temperature of the snow rises slowly until it reaches 0° C. Provided that the mixture is stirred constantly, it remains at that point until all the snow has changed to water. When all the snow melts, the temperature begins to rise again. A definite amount of heat is required to change the snow to water at the same temperature. This heat is required to change the water molecules from crystal form to liquid form.

It has been proved by many experiments that 80 calories of heat are required to change 1 gram of ice at 0° C to water at 0° C. In terms of English units, the heat required to change 1 pound of ice at 32° F to water at 32° F is 144 Btu. The quantity of heat in each of these expressions is called the HEAT OF FUSION of water. The heat which is used while the ice is melting represents the work done to produce the change of state. Since 80 calories are required to change a gram of ice to water at 0° C, it follows that a gram of water gives up 80 calories during the freezing process.

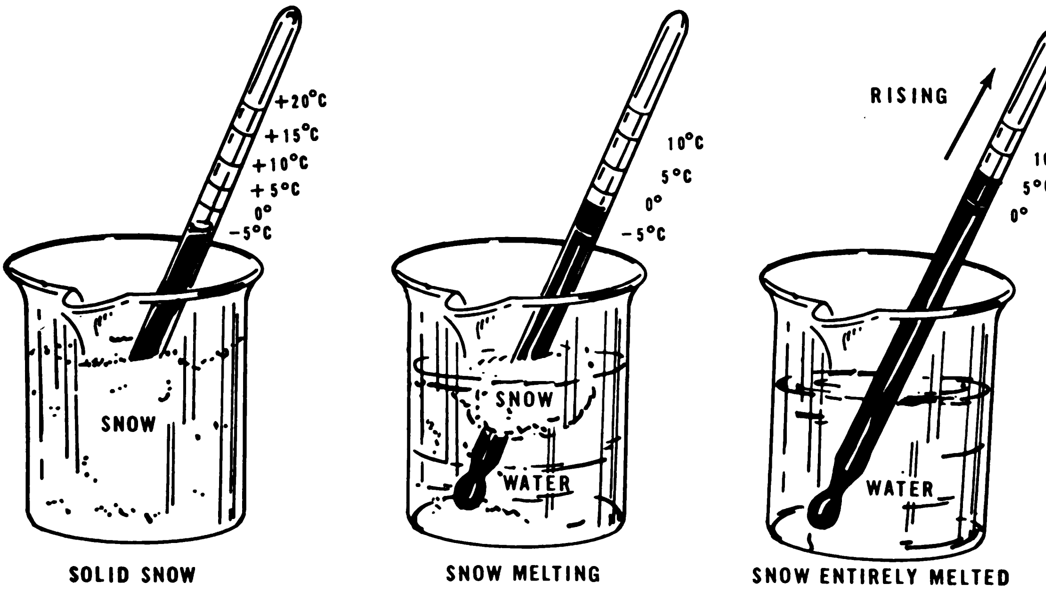


Figure 3-12.—Observing the temperature of melting snow.

Many substances behave very much like water. At a given pressure, they have a definite heat of fusion and an exact melting point. There are many materials, however, which do not change from a liquid to a solid state at one temperature. Molasses, for example, gets thicker and thicker as the temperature decreases; but there is no exact temperature at which the change of state occurs. Wax, celluloid, clay, and glass are other substances which do not change from a liquid to a solid state at any particular temperature. In fact, measurements of the glass thickness at the bottom of windows in ancient cathedrals tend to indicate that the glass is still flowing at an extremely slow rate.

Another change of state is evaporation (vaporization). For example, damp clothing dries rapidly under a hot flatiron but not under a cold one. A pool of water evaporates more rapidly in the sun than in the shade. From these familiar facts you may conclude that heat has something to do with evaporation. The process of changing a liquid to a vapor is similar to that which occurs when a solid melts.

If a given quantity of water is heated until it evaporates—that is, changes to a gas (vapor)—a much greater amount of heat is used than that which is necessary to raise the same amount of water to the boiling point. For example, several hundred calories are required to change 1 gram of water to vapor at a given temperature. It takes 972 Btu to change 1 pound of water at 212° F to water vapor (steam) at 212° F. The amoun heat that is necessary for this change is ca the HEAT OF VAPORIZATION of water. Fig 3-13 illustrates the principle that over five ti

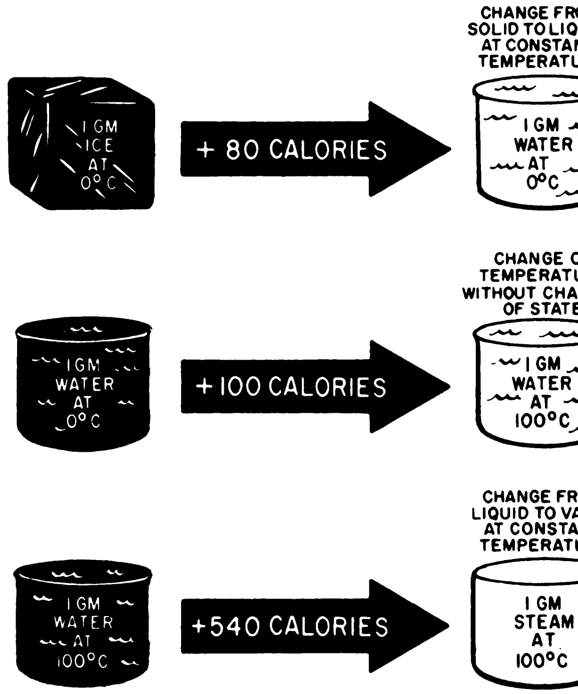


Figure 3-13.—A large amount of heat is needed to vaporize water.

as much heat is required to change a given amount of water to vapor than is required to raise the same amount of water from the freezing to the boiling point.

When water is heated, some vapor forms before the boiling point is reached. This change from water to vapor occurs as follows: As the water molecules take up more and more energy from the heating source, their kinetic energy increases. The motion resulting from the high kinetic energies of the water molecules causes a pressure which is called the vapor pressure. As the velocity of the molecules increases, the vapor pressure increases. The BOILING POINT of a liquid is that temperature, at a given atmospheric or external pressure, at which the vapor pressure equals the external pressure. At normal atmospheric pressure at sea level (29.92 inches of mercury), the boiling point of water is 100° C or 212° F.

While the water is below the boiling point, a number of molecules acquire enough kinetic energy to break away from the liquid state into a vapor. For this reason some evaporation takes place slowly below the boiling point. At the boiling point or above, large numbers of molecules have enough energy to change from liquid to vapor and the evaporation takes place much more rapidly.

If the molecules of water are changing to water vapor in an open space, the air currents carry them away quickly. In a closed container, they rapidly become crowded and some of them bounce back into the liquid as a result of collisions. When as many molecules are returning to the liquid state as are leaving it, the vapor is said to be saturated. Experiments have shown that saturated vapor in a closed container exerts a pressure and has a given density at every temperature.

Thermometry

The measurement of temperature is known as thermometry. If an object is hot to the touch, it can be said that it has a high temperature; and if it is cold to the touch, it has a low temperature. In other words, temperature is used as a measure of the hotness or coldness of an object when it is being described. However, hotness and coldness are only relative. For example, on a cold day, metals seem colder to the touch than nonmetals because they conduct heat away from the body more rapidly. Also, if you leave a warm room and go outside, the air seems cooler than it really is. If you are outside in the cold and come into a warmer place, you feel that the room is warmer than it really is. In other words, the temperature that a person feels depends upon the state of his body.

In ancient times there was no way of accurately measuring temperature. Galileo, the famous Italian scientist, was the first person to construct a thermometer. He chose gas as an expanding medium and, as might be expected, his thermometer was quite different from those that find extensive use today. Figure 3-14 is an illustration of a simple gas thermometer. When the gas in the flask is heated it expands, forcing the liquid in the tube downward. When the gas in the flask is cooled, it contracts and atmospheric pressure outside the tube pushes liquid back up into the tube.

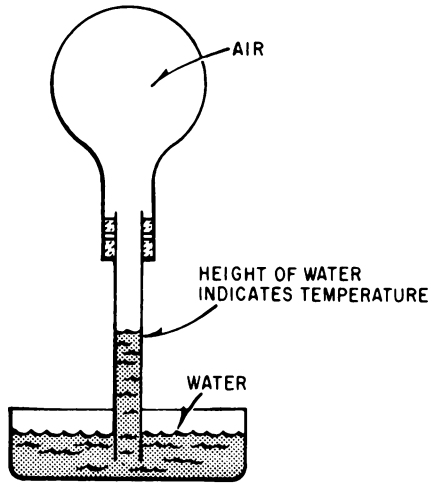


Figure 3-14.—Simple gas thermometer.

KINETIC THEORY.—In Galileo's time there was no simple explanation as to why the gas type thermometer worked. However, its operation can now be explained by the kinetic theory of temperature.

The kinetic theory of temperature may be presented by the following discussion. Since the number of molecules of any substance enclosed in a sealed container is constant, only the velocity of the motion of these molecules can be changed. According to the kinetic theory of gases, the pressure of a given number of molecules is determined by their molecular kinetic energy. The physical evidence of this relation is the presence of pressure in the closed container

as the molecules bombard against each other and against the retaining walls.

Heating causes the molecules of a substance to move more rapidly, and cooling causes them to move more slowly. Any increase of molecular motion in a closed container shows up as an increase of pressure. Thus the gas thermometer measures temperature indirectly, by measuring pressure changes.

THERMOMETERS.—Galileo's thermometer was based on a good idea, but it was unreliable because the thermometer was affected not only by the temperature but also by the atmospheric pressure. Because of this fault, liquids were used in later thermometers. Water was the first liquid used; but because it freezes at 0°C, it could not measure temperatures below that point. After much experimentation, scientists decided that the best liquids to use in the construction of thermometers are alcohol and mercury because of the low freezing points of these liquids.

The construction of the common laboratory thermometer gives some idea as to the meaning of a change of 1 degree in temperature. A bulb is blown at one end of a piece of glass tubing of small bore. The tube and bulb are then filled with the liquid to be used. The temperatures of both the liquid and the tube during this process are kept at a point higher than the thermometer will ever reach in normal usage. The glass tube is then sealed and the thermometer is allowed to cool. During this cooling process, the liquid falls away from the top of the tube and creates a vacuum within the thermometer.

For marking, the thermometer is placed in melting ice. The height on the tube at which the liquid column comes to rest is marked as the 0° C point. Next, it is placed in steam at a pressure of 76 centimeters of mercury and a mark is made at that point on the glass tube to which the liquid inside rises. That is the boiling point or the 100°C. mark. The space between these two marks is then divided into 100 equal parts. These spacings are known as DEGREES. It is this type of thermometer that is used in almost all laboratory work, and in testing electrical equipment. It is commonly known as the CENTIGRADE thermometer, and is sometimes also called the Celsius thermometer.

In English-speaking countries, the FAHRENHEIT thermometer is commonly used for other than physical or chemical laboratory purposes. The freezing point is marked 32 and the boiling point is marked 212. The space between these marks is divided into 180 equal parts. These divisions are Fahrenheit degrees, named after the scientist who made the first thermometer of this type. Most weather reports and room temperatures are given in Fahrenheit degrees.

Because there are two systems of temperature measurement, it is frequently necessary to convert from one to the other. Instead of attempting to memorize an equation, it is easy to reason the conversion from one scale to the other. The range on the centigrade thermometer from the freezing point to the boiling point is 100°C , and the same range on the Fahrenheit thermometer is 180°F. Thus, you can readily see that over the same temperature range the liquid moves 180 divisions on the Fahrenheit scale for every 100 divisions on the centigrade scale. A change of 5 degrees on the centigrade scale, therefore, is equal to a change of 9 degrees on the Fahrenheit scale. (The ratio 100/180 reduces to 5/9.) This ratio now enables you to compute in one scale from a reading in the other. Because zero on the centigrade scale corresponds to 32 degrees on the Fahrenheit scale, a difference in reference points exists between the two scales. (See fig. 3-15.)

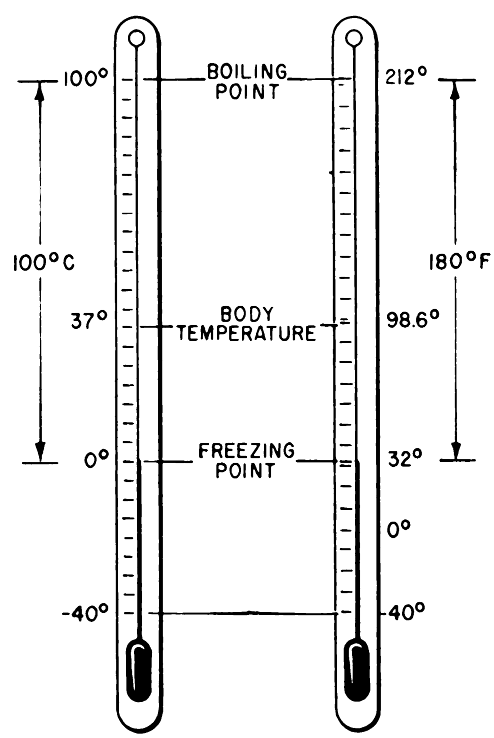


Figure 3-15.—Fahrenheit and centigrade thermometers.

To convert from the Fahrenheit scale to the centigrade scale, subtract this 32-degree difference and multiply the result by 5/9. As an example, convert 68°F. to centigrade--

$$68 - 32 = 36$$
$$36 \times \frac{5}{9} = 20° \text{ C}$$

To convert centigrade to Fahrenheit, the reverse procedure is necessary. First multiply the reading on the centigrade thermometer by 9/5 and then add 32 to the result—

$$20 \times \frac{9}{5} = 36$$
$$36 + 32 = 68° \text{ F}$$

An easy way to remember where to use 9/5 and where to use 5/9 is to keep in mind that the Fahrenheit scale has more divisions than the centigrade scale. Thus, in going from Fahrenheit to centigrade, multiply by the ratio that is smaller; in going from centigrade to Fahrenheit, use the larger ratio.

Another method of temperature conversion which uses these same ratios is based on the fact that the Fahrenheit and centigrade scales both register the same temperature at -40 degrees; that is, -40°F equals -40°C. This method of conversion, sometimes called the "40 rule," proceeds as follows:

1. Add 40 to the temperature which is to be converted. Do this regardless of whether the given temperature is Fahrenheit or centigrade.
2. Multiply the result of step 1 by 9/5 if you are changing centigrade to Fahrenheit; by 5/9 if you are changing Fahrenheit to centigrade.
3. Subtract 40 from the result of step 2. This is the answer. This simple process can be summarized: Add 40, multiply by the appropriate fraction, and then subtract 40.

As an example to show how the 40 rule is used, let us convert 100°C. to the equivalent Fahrenheit temperature:

$$100 + 40 = 140$$
$$140 \times 9/5 = 252$$
$$252 - 40 = 212$$

Therefore, 100° C = 212° F. For practice, try converting from 212° F to 100° C or from 32° F to 0°C. Remember that the multiplying ratio for converting F to C is 5/9, rather than 9/5. Also remember that you always ADD 40 first, then multiply, then SUBTRACT 40, regardless of which direction the conversion is going.

It is important that AE's be able to read thermometers and to convert from one scale to the other. In some types of electrical equipment, thermometers are provided as a check on operating temperatures. Thermometers are also used to check the temperature of a charging battery.

Because the range of all liquid thermometers is extremely limited, it is at once apparent that other methods of thermometry are necessary. Most liquids freeze at temperatures between 0° and -200° C. At the upper end of the temperature range, where high heats are encountered, the use of liquid thermometers is limited by the high vapor pressures of those liquids. Among the most widely used types of thermometers other than the standard liquid thermometers are the RESISTANCE THERMOMETER and the THERMOCOUPLE.

The resistance thermometer makes use of the fact that the resistance of metals changes as the temperature changes. This thermometer is usually constructed of platinum wire wound on a mica form and enclosed in a thin-walled silver tube. It is extremely accurate from the lowest temperature to the melting point of the unit.

The thermocouple shown in figure 3-16 is essentially an electric circuit that makes use of the principle that when two unlike metals are joined and the junction is at a different temperature than the remainder of the circuit, an electromotive force is set up. This electromotive force can be measured with great accuracy by a galvanometer. Thermocouples can be located at any point in a machine where the temperature is important.

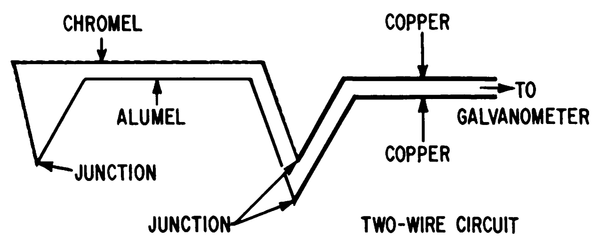


Figure 3-16.—Thermocouple.

Wires can be run from the thermocouples to the galvanometer which can be located at any convenient point. By means of a switch, one galvanometer can read the temperatures of a number of widely separated points.

EXPANSION

A good example of the expansion and contraction of substances is the ball and ring, illustrated in figure 3-17. The ball and ring are made of iron. When they are both the same temperature, the ball barely slips through the ring. When the balls is heated or the ring is cooled, however, the ball does not slip through the ring.

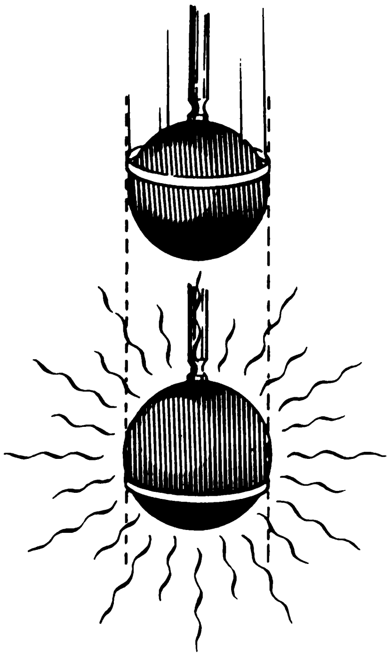


Figure 3-17.—Ball and ring.

Experiments show that for a given change in temperature, the change in length or volume is different for each substance. For example, a given change in temperature causes a piece of copper to expand nearly twice as much as a piece of glass of the same size and shape. For this reason, the lead wires into an electronic tube cannot be made of copper but must be made of a metal that expands at the same rate as glass. If the metal does not expand at the same rate as the glass, the vacuum in the tube is broken by air leaking past the wires in the glass stem. The metal usually used for this purpose is an alloy called "Covar."

Because some substances expand more than others, it is necessary to measure experimentally the exact rate of expansion of each one. The amount that a unit length of any substance expands for a 1-degree rise in temperature is known as the coefficient of linear expansion for that substance.

Coefficients of Expansion

To estimate the expansion of any object, such as a steel rail, it is necessary to know three things about it—its length, the rise in temperature to which it is subjected, and its coefficient of expansion. This relationship is expressed by the equation:

$$\text{Expansion} = \frac{(\text{coefficient}) \times (\text{length})}{\times\ (\text{rise in temperature})}$$

$$e = kL(t_2 - t_1)$$

In this equation, the letter k represents the coefficient of expansion for the particular substance. In some instances, the Greek letter (alpha) is used to indicate the coefficient of linear expansion.

If a steel rod measures exactly 9 feet at 21° C, what is its length at 55° C? The value of k or α for steel is 11×10^{-6}. If the equation $e = kL(t_2 - t_1)$ is used, then:

$$e = (11 \times 10^{-6}) \times 9 \times (55 - 21)$$
$$e = 0.000011 \times 9 \times 34$$
$$e = 0.003366$$

This amount, when added to the original length of the rod, makes the rod 9.003366 feet long.

The increase in the length of the rod is relatively small; but if the rod were placed where it could not expand freely, there would be a tremendous force exerted due to thermal expansion. Thus, thermal expansion must be taken into consideration when designing ships, buildings, and all forms of machinery.

Table 3-6 is a list of the coefficients of linear expansion of some substances.

Table 3-6.—Expansion coefficients.

Substance	Coefficient of linear expansion (per degree C)
Aluminum	24×10^{-6}
Brass	19×10^{-6}
Copper	17×10^{-6}
Covar	4 to 9×10^{-6}
Glass	4 to 9×10^{-6}
Quartz	0.4×10^{-6}
Steel	11×10^{-6}
Zinc	26×10^{-6}

A practical application of the differences in the coefficients of linear expansion is the thermostat. This instrument consists of an arrangement of two bars of dissimilar metal fastened together so that when the temperature changes a bending takes place due to the unequal expansion of the metals. Figure 3-18 shows such an arrangement, made with a wooden handle so that it may be held in the hand for laboratory demonstrations. Thermostats are used in overload relays for motors, in temperature-sensitive switches, and in heating systems. Figure 3-19 is an illustration of a typical thermostat used in a heating system. The two dissimilar metals are thin strips fastened back to back and bent into a curve. When the compound bar of dissimilar metals consists of thin strips, the arrangement is often called a bimetallic strip.

The coefficient of surface or area expansion is approximately twice the coefficient of linear expansion. The coefficient of volume expansion is approximately three times the coefficient of linear expansion. It is interesting to note that in a plate containing a hole, the area of the hole expands at the same rate as the surrounding material. In the case of a volume enclosed by a thin solid wall, the volume expands at the same rate as would a solid body of the material of which the walls are made.

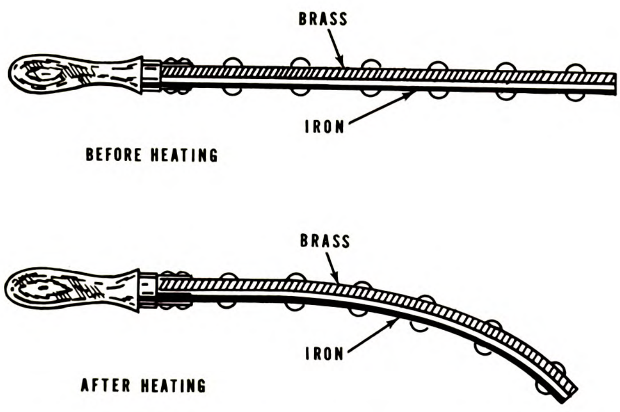


Figure 3-18.—Compound bar.

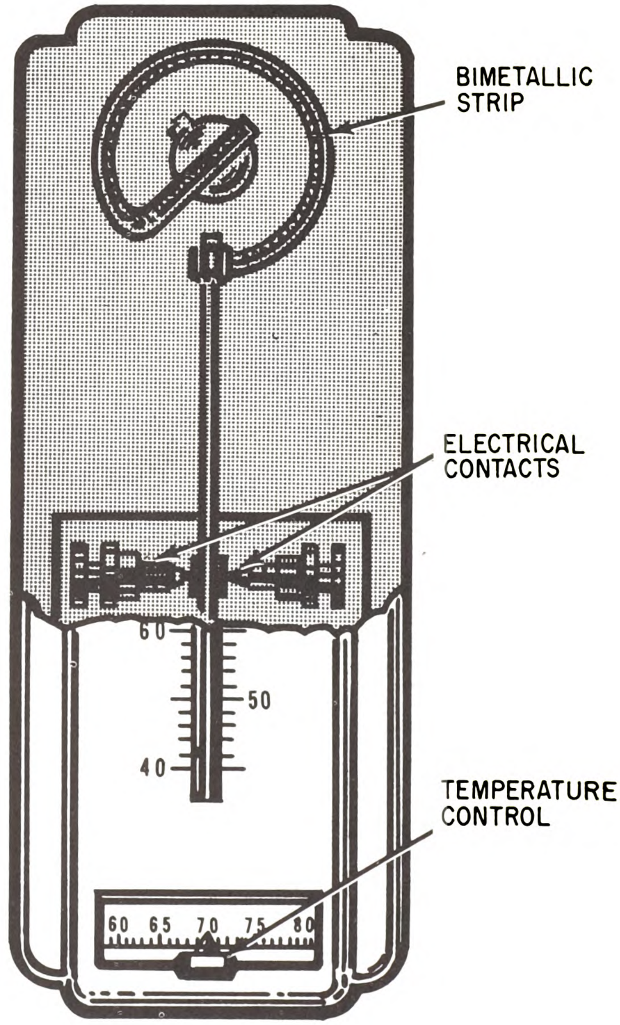


Figure 3-19.—Thermostat.

CHAPTER 4

POWER DISTRIBUTION AND ASSOCIATED HARDWARE

In order for the Aviation Electrician's Mate to maintain aircraft electrical equipment, it is necessary that he have an understanding of the various aircraft electrical power systems and their associated equipment. He must also have a fundamental knowledge of the means by which aircraft electrical power is produced, regulated, controlled, and distributed. With this basic understanding, he will be able to recognize and analyze electrical problems and take corrective action.

One of the first uses of electric power in aircraft occurred in 1915 when a standard shipboard radio set with a battery power supply was first installed in an aircraft. By the beginning of World War I, it had been determined that airborne radio was practical and installations were made in aircraft, using 45-volt dry cell batteries and 6-volt storage batteries.

Most early Navy aircraft engines obtained ignition power from a d-c, 8-volt, engine-driven generator, controlled by a vibrating type voltage regulator and cutout and an 8-volt storage battery.

In about 1932 a big change occurred in aircraft electric power supplies. One system was made to supply all of the aircraft electric power. Ignition generators were replaced by magnetos. Two types of generators were first used to supply this power system. One type was the dual-voltage (12-volt and 1,000-volt) d-c generator. The other type was the a-c/d-c generator, which for the first time introduced the slipping clutch that permitted the a-c frequency to be held somewhat constant over a wide range of engine rpm. A-c voltage regulation was not yet available; but since the d-c field supplied excitation to both the a-c and d-c sections, the d-c voltage regulation held the a-c voltage reasonably constant. Soon thereafter the straight low voltage d-c generator was used in some aircraft. This generator was a 12-volt regulated unit to supply power for battery charging, radio transmitter, radio receiver and lighting. A dynamotor was provided in the transmitter to obtain high voltage d.c.

From 1932 to 1941 little change was made in aircraft electric power systems. Some progress was made in the improvement of components; but it was not until just prior to World War II that the demand for electric power on naval aircraft began to increase rapidly and major changes in electric power systems were made. As the size of aircraft generators grew, weight became an increasingly important factor. Several steps were taken to decrease weight. Systems were raised from 12 to 28 volts, resulting in some saving in generator and aircra.t wiring weight. Generators became universally blast cooled, and engine accessory gearing was changed to operate generators at higher speeds. The most popular systems were those using straight d-c generators to supply 28-volt d-c power and using inverters to change a portion of this power to 115 volts a.c. However, by the end of World War II many aircraft electric power systems, particularly those in patrol aircraft, began to require more power than this practical limit. The 3-phase, 120/208-volt, a-c power system proved to be the answer.

Many naval aircraft contain two or more electrical systems: a d-c system, which supplies direct current at 24 to 28 volts; and one or more a-c systems. Basically, a-c electrical systems for aircraft can be classified as either variable frequency or constant frequency. Recent aircraft designs are almost exclusively constant frequency a-c systems with very little variable frequency a-c power installed. The variable frequency system is suitable for applications that are not critical to frequency and generally supplies the bulk of the a-c load. The constant frequency system, however, is suitable for these applications as well as those requiring a frequency remaining between well-defined limits, such as synchros and servosystems. With the expanding use of constant-speed drive units

in jet aircraft, the constant frequency system is becoming more popular.

External power receptacles are located on the aircraft and provide a means of attaching external sources of power to the aircraft for engine starting and ground operation of the electrical and electronic equipment. In addition to this, many of the larger aircraft are also equipped with an auxiliary powerplant (APP) to provide power in emergencies, while the aircraft is on the ground, or during water operations. These powerplants contain a generator for supplying power to the aircraft's electrical system. The generator, depending on the type of aircraft, is driven by an independently operated reciprocating or turbine engine. The turbine engine uses JP fuel and is becoming the prevalent engine in recent aircraft designs.

These sources of power are connected through switches and control equipment to a bus system of which the primary bus is often one part. The primary bus consists of a copper bar, or bars, fitted with bolt connections for the attachment of feeder lines. The connections are enclosed in metal junction boxes; covers to these boxes are frequently made of synthetic materials such as Fiberglas, particularly in current models. In small aircraft, the primary bus connects the power through fuses or circuit breakers to the electrical equipment. In larger aircraft, the primary bus connects the sources of power through a system of feeder lines to a number of individual buses and distribution panels located at various stations within the aircraft.

Usually the d-c system is divided into two or more separate buses. The essential, or emergency, bus system is provided to connect power to the flight instruments in the event of power failure of the primary bus. A few circuits are not connected through either the essential or the primary bus, but are connected directly to the battery and have power available to them at all times. These consist of submersion actuator circuits and those lights and devices necessary for the initial boarding of the aircraft. The d-c secondary bus is lost when main power sources are lost but can be recovered when the power switch is in BAT position or the wheels are lowered. The d-c monitored bus is lost whenever the main power sources are lost and cannot be recovered. Only nonessential loads are connected to this bus.

AIRCRAFT WIRE AND CABLES

An important part of aircraft electrical maintenance is determining the correct wire or cable for a given job. For purposes of electric installations, a wire is described as a stranded conductor, covered with an insulating material. The term cable, as used in aircraft electrical installations, includes the following: Two or more insulated conductors contained in the same jacket (multiconductor cable); two or more insulated conductors twisted together (twisted pair); one or more insulated conductors covered with a metallic braided shield (shielded cable); a single insulated center conductor with a metallic braided outer conductor (RF cable).

For wire replacement work, the aircraft's Maintenance Instructions Manual should first be consulted since it normally lists the wire used in a given aircraft. When this information cannot be obtained from the manual, the AE must select the correct size and type of wire needed. The factors used in determining correct wire size are explained in Basic Electricity, NavPers 10086-A, and Installation Practices for Aircraft Electric and Electronic Wiring, NavAer 01-1A-505. The procedures specified in this publication are mandatory for the maintenance of naval aircraft; therefore, it is important that the AE become familiar with and follow the instructions.

The information given in these two publications plus that given in Military Specification MIL-W-5088B should enable the AE to make the correct selection. The data necessary to determine the correct wire for a given application may be summarized as follows:

1. Current drawn by the load.
2. Length of wire required to go from the source to the load.
3. Allowable voltage drop between the source or point of voltage regulation and the load.
4. The maximum voltage that is applied to the wire.
5. The approximate ambient air temperature where the wire is installed.
6. Whether the conductor is a stranded wire in free air or one of a group of wires in a bundle or in a conduit.

Table 4-1 shows the current-carrying capacity of copper and aluminum wires and cables.

After the wire size has been determined, the characteristics of its insulation should be considered. The following descriptions of the various military specifications will help in selecting the correctly insulated wire for a specific need.

Table 4-1.—Current-carrying capacity of stranded wires and cables.

Wire or cable size			Continuous-duty current—amperes	
Aluminum	Copper	Approx. *wire gage	Single wire in free air	Wires and cables in conduit or bundles
	AN-22	19	. . . .	5
	AN-20	17	11	7.5
	AN-18	15	16	10
	AN-16	14	22	13
	AN-14	12	32	17
	AN-12	10	41	23
	AN-10	8	55	33
	AN-8	5	73	46
	AN-6	3	101	60
	AN-4	1	135	80
	AN-2	11/32	181	100
	AN-1	25/64	211	125
	AN-0	7/16	245	150
	AN-00	31/64	283	175
	AN-000.	35/64	328	200
	AN-0000. . . .	39/64	380	225
AL-8	. . . .	6	60	36
AL-6	. . . .	4	83	50
AL-4	. . . .	1	108	66
AL-2	. . . .	0	152	82
AL-1	. . . .	23/64	174	105
AL-0	. . . .	13/32	202	123
AL-00 . . .	. . . .	15/32	235	145
AL-000. . .	. . . .	33/64	266	162
AL-0000 . .	. . . .	37/64	303	190

*Smallest slot of the wire gage that the stranded wire will pass through easily. Diameter is in inches for the larger wires. This method is merely a rough approximation to be used in the field only when complete wire tables are not available.

These military specification numbers are given on the reel, spool, or other shipping container.

MIL-W-5086A single conductor copper wire (600 volts) is general-purpose wire and is the most commonly used in aircraft wiring systems. It consists of a stranded copper conductor with insulation that is resistant to abrasion, moisture, aircraft engine oils, and also partially resistant to flame and fungus. The voltage rating of the insulation is 600 volts maximum. Temperature limits are conductor temperature rating 105° C (220°F) and ambient temperature rating 65°C (150°F).

MIL-W-7072B aluminum single conductor wire (600 volts) is made up of stranded aluminum conductors and is covered with an insulation that has the same properties as that on MIL-W-5086A wire. Aluminum wire has 1.6 times the resistivity of copper, but is only 1/3 as heavy. Temperature limits are conductor temperature rating 105°C (220°F) and ambient temperature rating 65°C (150°F). This wire may be used only in BuWeps approved applications.

MIL-W-7139B single conductor, high temperature wire (600 volts) is stranded insulated copper wire, designed to be capable of operating

continuously with the conductor's total temperature as high as 400°F and ambient temperature rating 155°C (310°F). Its insulation is designed to assure short-time emergency operation of electrical circuits in the event of fire, and to be resistant to abrasion, fuel oils, and moisture as encountered in aircraft. The strands of this wire are coated with pure silver.

MIL-C-7078A shielded single and multiconductor cable (600 volts) is available in two types. Type I is shielded and contains from 1 to 7 stranded conductors, each of which conforms to the conductor requirements described in MIL-W-5086A. Type II has a nylon jacket over the shield. With the exception of the shield, the insulation characteristics of this wire are identical to those for wires manufactured in accordance with MIL-W-5086A.

MIL-C-25038B fire alarm detector wire (125 volts) is a type of stranded wire designed for use in fire detection systems in aircraft engines. It is highly resistant to flame due to its insulation of asbestos or glass braid. Insulation is rated at 125 volts, and will not break down at temperatures up to 650°F. It has relatively poor abrasion, moisture, and fuel oil resistance. Generally, fuel oils and moisture are not present where this type of wire is used.

MIL-C-3702 ignition, high-tension, single-conductor cable is a stranded, high-tension, insulated ignition cable for the ignition systems of internal combustion engines for aircraft, automotive vehicles, and marine service.

MIL-W-76B insulated hookup wire and cable is a synthetic-resin insulated electrical hookup wire or cable. It is used for the internal wiring of electrical and electronic equipment.

ALUMINUM WIRE

The use of aluminum wire in aircraft has been well established and will probably increase because of its weight saving characteristics, its greater availability in time of war, and lower cost. Therefore, it is appropriate to note some of the unusual properties of aluminum and the precautions that must be observed in its use.

Aluminum is unusual in that it forms an electrically resistant oxide film on all of its surfaces; it has an inherent property known as "creep" which makes proper installation of a terminal extremely critical. Creep is the tendency of aluminum to actually flow away from the point where pressure is applied. Aluminum is softer than copper, and reacts chemically when placed in direct contact with it.

The electrically resistant aluminum oxide film is always present and must be either penetrated or removed in order to guarantee a satisfactory electrical connection. A compound called Penetrox A is used to remove this film. Initially, tin-plated terminals and splices are supplied so that no oxide film is present. If the terminals have become dirty due to storage or excessive handling, they should be cleaned by wiping with a soft cloth. Never use a wire brush or any abrasive method to clean a tinned aluminum surface.

One of the troublesome problems resulting from the use of aluminum wire is that caused by dissimilar metals. This problem occurs frequently when aluminum and copper are placed side by side. As soon as moisture accumulates between the two metals, an electrical differential exists which produces a "battery effect." This effect results in greater corrosion.

To reduce the undesirable effects caused by aluminum's softness, creep, and oxide film forming, these techniques should be followed:

1. Select the proper size of wire and terminal. AL or ALUM is stamped on terminals and splices for use with aluminum wire.
2. Select the proper handtool when crimping.
3. Handle the aluminum wire carefully and use the proper assembly procedure when preparing it for an electrical connection.
4. Thoroughly clean any terminals used.
5. Be careful not to scrape or nick the wire when stripping.

ELECTRICAL DIAGRAMS AND SYMBOLS

A large part of any AE's work consists of dealing with cable groups and harnesses. He may often be required to secure cable terminals onto switches, circuit breakers, and other components; lace cable harnesses; and trace individual wires and cables between units of equipment. Occasionally, he may be called upon to install or reroute cable groups.

Symbols

Diagrams of electrical circuits use symbols to indicate circuit components and equipment. Appendix III shows some of the standard symbols used in electrical circuit diagrams. For a complete listing of electrical and electronics symbols, consult Military Standard MIL-STD-15-1.

Diagrams

Electrical diagrams may be classified as either wiring diagrams or schematic diagrams. When installing or repairing equipment, the AE will use both types of these electrical "blueprints."

The major purpose of the schematic diagram is to establish the electrical operation of a particular system. It is usually the first drawing worked out by the designer. It denotes the scheme of things. It is not drawn to scale, and it shows none of the actual construction details of the system, such as physical location in the aircraft, wire routing, or any other detail unless it is essential in explaining the operation of the system. Figure 4-1 shows a typical schematic diagram of the ignition and starter circuit of a naval aircraft.

The wiring diagram presents detailed circuitry information on all electrical and electronic systems. It includes the equipment part number which is located adjacent to the part. This diagram should be consulted when checking or replacing wiring or other equipment and when trouble-shooting a system. Figure 4-2 is a wiring diagram of the same system shown in the schematic diagram of figure 4-1. By comparing these, the AE can easily see that the wiring diagram would be more difficult to use when learning how the circuit functions; however, it should be noted that this diagram gives considerably more information than the schematic.

The wiring diagram shows in detail how a wire is routed between components. Each segment of the complete run is shown, along with its identification number, as well as each plug or terminal strip used.

A master wiring diagram is a single diagram that shows all the wiring in an aircraft. Since, in most cases, these would be so large that their use would be impractical, they are broken down into logical sections, such as the d-c power system, the a-c power system, and the aircraft lighting system.

Diagrams of major circuits generally include an isometric shadow outline of the aircraft showing the location of items of equipment involved and the routing of interconnecting cables. (See fig. 4-3 (A).) A cable, regardless of the number of conductors, is represented on an isometric wiring diagram by a single line, and no attempt is made to show the proper connections in connection boxes or at components. An isometric type drawing thus shows at a glance a rough picture of the entire circuit's layout. Isometric

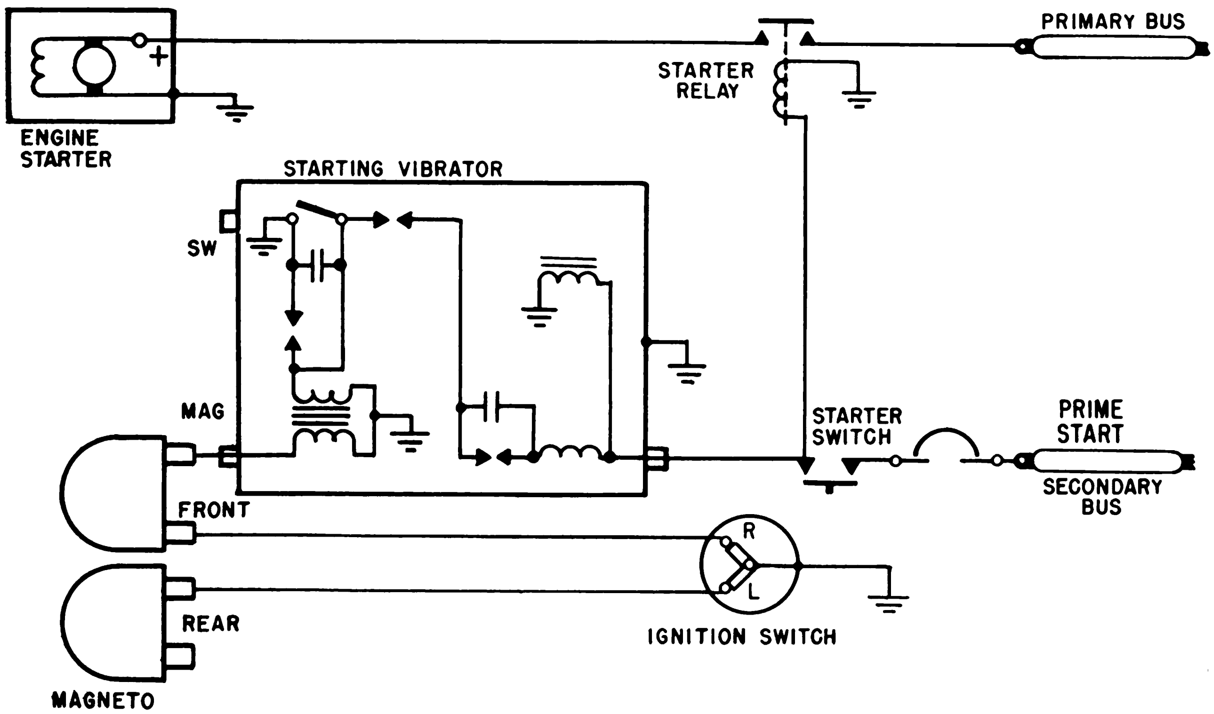


Figure 4-1.—Typical schematic diagram.

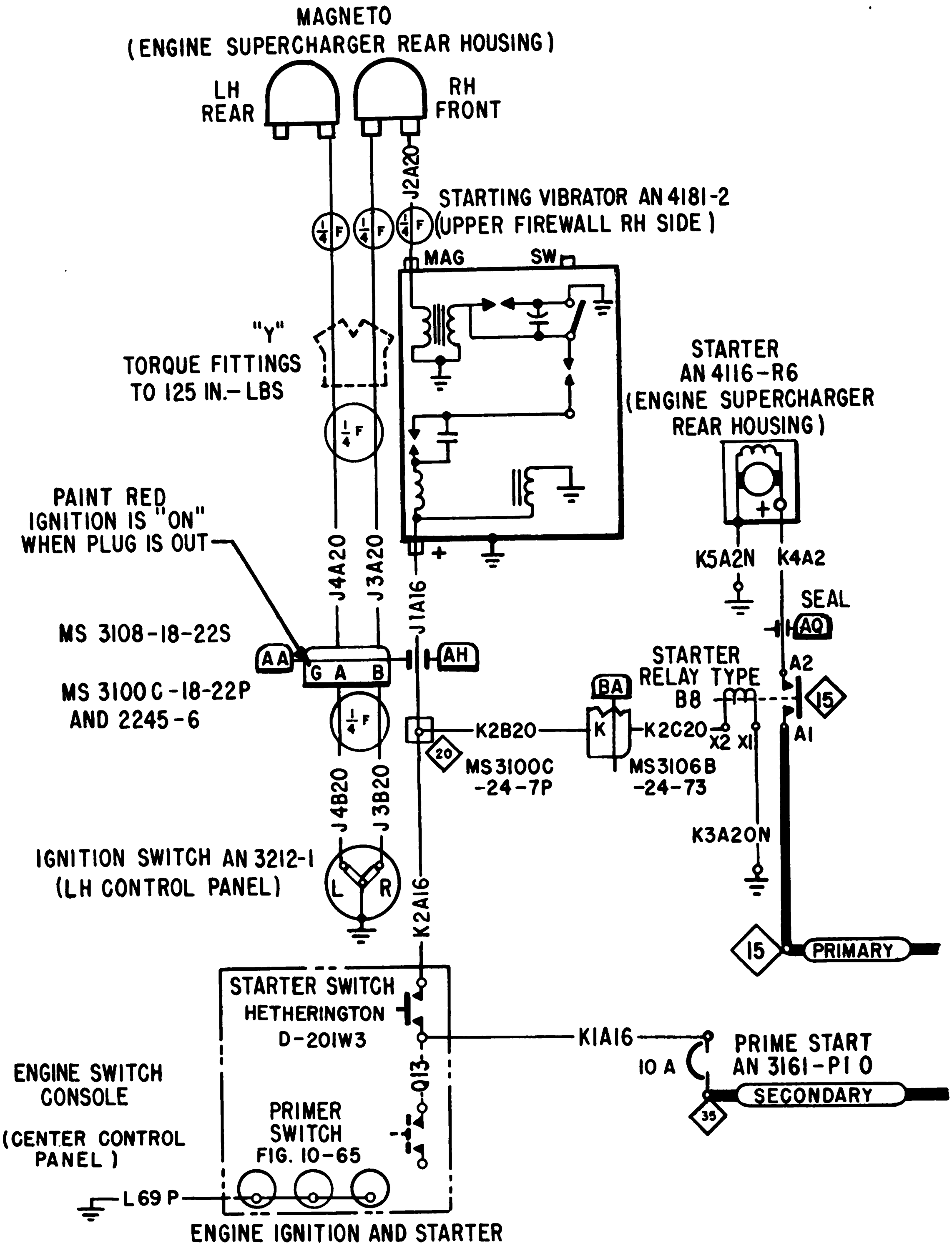


Figure 4-2.—Typical wiring diagram.

wiring diagrams of lighting and power circuits are usually used to indicate only the main supply cables, feeders, and their associated equipment.

A further breakdown of the master wiring diagram is the circuit diagram. For example, the lighting system may be broken down into the forward compartment light circuit, lower deck light circuit, flight instrument light circuit, nonflight instrument circuit, etc.

By breaking a system into circuit diagrams, the individual circuits may be more easily traced, thus maintenance and testing may be accomplished more easily. Figure 4-3 (B) shows a circuit wiring diagram of an aircraft carburetor air temperature indicator circuit.

By closely comparing the various types of diagrams that have been shown, the AE can see how they differ and how each serves a particular purpose that the other does not accomplish.

Wire and Cable Identification System

To make maintenance easier, each interconnecting wire cable installed in an aircraft is marked with a combination of letters and numbers which identify the wire, the circuit to which it belongs, its gage size, and other information necessary to relate the wire to a wiring diagram. This marking is called the cable identification code. Details of the code are specified in MIL-W-5088B.

The basic wire identification code used for all circuits except those having the circuit function letters R, S, T, or Y is as shown in figure 4-4 (A).

1. Unit Number—Prefixed where necessary to distinguish between wires in a circuit having identical items of equipment and identification numbers.
2. Circuit Function Letter—Used to identify the function of the particular circuit. (See MIL-W-5088B for details.)
3. Wire Number—Used to distinguish between wire with the same circuit function letter.
4. Wire Segment Letter—Used to distinguish between conductor segments in a particular circuit.
5. Wire Size Number—Used to designate AN or AL gage size of the wire. Wire size is omitted on coaxial cable. Wire size number is replaced with a dash for thermocouple wire.
6. Ground, Phase, or Thermocouple Letter—Used to denote a wire to ground, phase of a wire in a 3-phase system, or materials of a thermocouple pair.

The identification code for circuits R, S, and T (radio, radar, and special electronic circuits), in addition to the basic numbers and letters listed above, includes another letter after the circuit function letter. This letter is called the circuit designation letter and further identifies the circuit inside the system. (See fig. 4-4 (B).) (For additional information refer to MIL-W-5088B.)

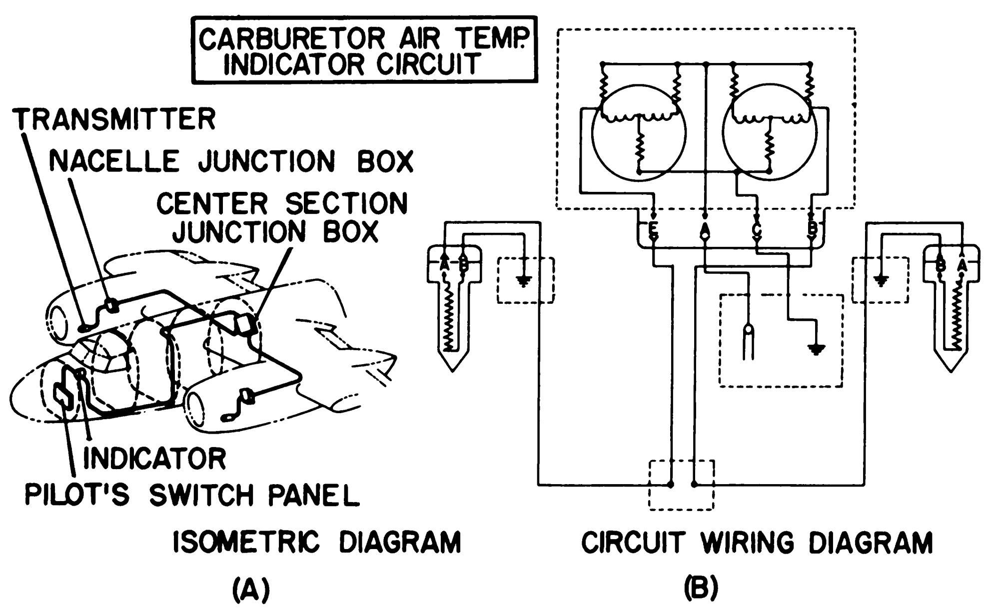


Figure 4-3.—Sample circuit wiring diagram.

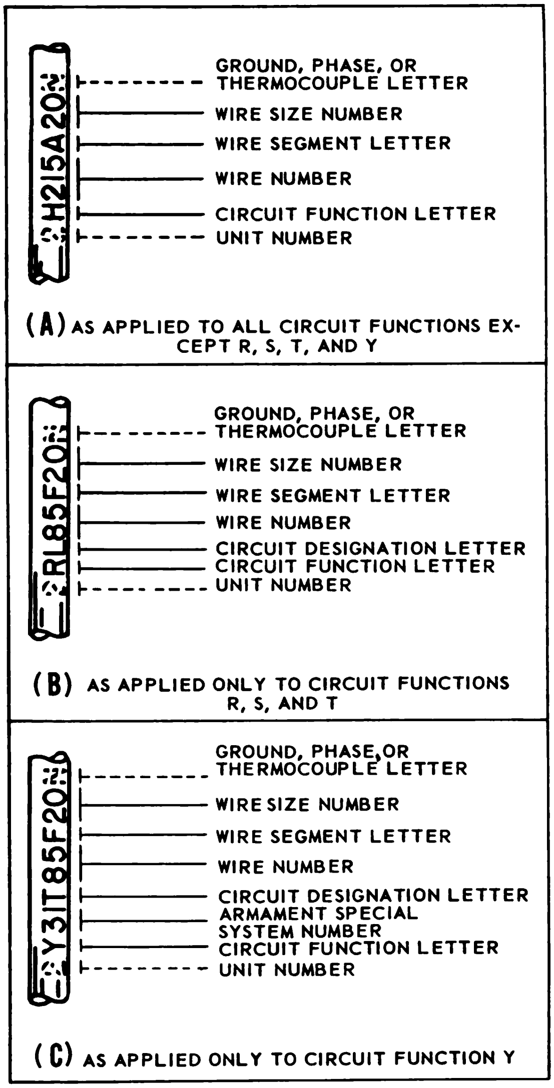


Figure 4-4.—Examples of wire identification coding.

When the circuit function letter is Y (indicating a special armament system), the basic code with the addition of a circuit designation letter is used along with the number of the particular armament system inserted after the circuit function letter. (See fig. 4-4 (C).)

When replacing terminals, splicing, or replacing a damaged wire, renumber the wire properly. If there is no identification number on the wire before repair, or if the number is illegible, determine the correct number from the electrical wiring diagram. Identification characters are either machine stamped or cut from numbered cellulose tape. If numbered tape is not available, white adhesive tape or white paper and clear cellulose tape may be used.

The preferred method of identification is to stamp the identification marking directly on the wire or cable with a hot foil stamping machine. If the wire insulation or outer covering will not stamp easily, lengths of insulating tubing (sleeves) are stamped with the identification marking and installed on the wire or cable.

When performing wire work, consult the electrical section of the Maintenance Instructions Manual for the particular aircraft involved. This section contains an explanation of the wiring identification (numbering) system for the aircraft, a table of the circuit functions and designation letters, and a symbol chart that explains the graphic symbols used in the wiring diagrams for that particular manual. This section contains all of the electrical diagrams for the particular aircraft.

A Military Standard color code has also established a uniform wiring code for circuit identification. The standard colors to be used in chassis wiring for the purpose of circuit identifiction of the equipment is given in table 4-2.

Table 4-2.—Standard color code chassis wiring.

Circuit	Color
Grounds, grounded elements, and returns.	Black.
Heaters or filaments, offground.	Brown.
Power supply B plus.	Red.
Screen grids.	Orange.
Cathodes.	Yellow.
Control grids.	Green.
Plates.	Blue.
Power supply, minus.	Violet (purple).
A-c power lines.	Gray.
Miscellaneous, above or below ground returns, AVC, etc.	White.

WIRING

Wiring Failures

Wires and cables should be installed and routed in such a manner that they are protected against the following common causes of wiring failure:

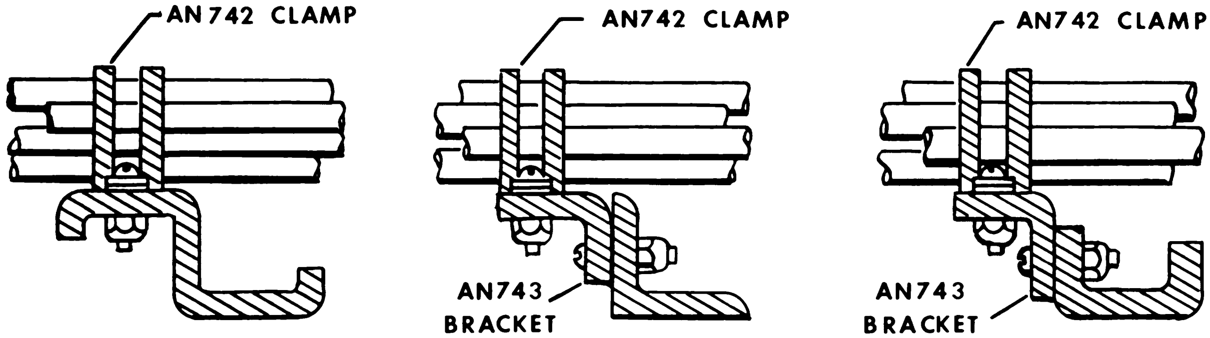


Figure 4-5.—Cable installation.

1. Chafing. (Wear of the insulation caused by frictional action against an object, such as a terminal, control cable, and structural member.) Correct installation of cables passing over structural members showing the cables properly supported and protected from chafing by use of cable clamps and brackets is shown in figure 4-5.
2. Use of wires and cables as handholds, or as support for personal belongings and equipment.
3. Damage by personnel moving within the aircraft.
4. Damage from cargo stowage or shifting.
5. Damage from battery acid fumes and fluids.
6. Abrasion in wheel wells where exposed to rocks, ice, mud, etc.

Junctions

Only approved devices, such as solderless type terminals, terminal blocks, connectors, disconnect splices, permanent splices, and feed-through bushings are to be used for cable junctions. Special attention must be given to insure that electrical connections are adequately protected from damage or short circuits resulting from movement of personnel, cargo, shell cases, clips, and other loose or stored materials.

Exposed junctions and buses should be protected with insulating materials. Junctions and buses located within enclosed areas containing only electrical and electronic equipment are not considered as exposed.

Electrical connections should be installed so that they are adequate both mechanically and electrically. Detailed information dealing with wiring specifications may be found in the latest revision of MIL-W-5088B.

Routing Cables

In the individual routing of cables, the aircraft is used to best advantage as an electrical shield for the cable. This shielding effect is used to reduce radio interference. In replacing a cable, take particular care to replace it in the exact position in which it was installed originally. Do not attempt to reduce the length of the cable by taking what may seem to be a logical shortcut.

The following routing procedures should be followed when performing cable work:

1. Wires and cables should be routed in such a manner that they are separated from lines containing flammable liquids, gases, and oxygen, and from their associated equipment.
2. Wires and cables installed in bilges and other locations where fluids may be trapped and the wires and cables contaminated must be properly routed and protected against fluid damage.
3. Where wires and cables are dressed downward to a connector, terminal block, panel or junction box, a trap or drip loop should be provided in the wires or cables to prevent fluids or condensate from running into the above devices. (Moistureproof connectors are exempt from this requirement.) If the cable leading to the connector is covered with insulating tubing, a drain hole should be provided at the bottom of the drip loop so accumulated liquid may drain out.
4. Wires and cables must be kept separate from high-temperature equipment, such as resistors, exhaust stacks, heating ducts, and deicers, to prevent cable insulation deterioration.
5. Excess slack should not be provided in wires and cables, except for drip loop and service requirements. However, enough slack should be provided to meet the following requirements:

a. Permit ease of maintenance.

b. Allow replacement of terminals at least two times, where practicable.

c. Prevent mechanical strain on the wires, cables, cable junctions, and cable supports.

d. Permit free movement of shock- and vibration-mounted equipment.

e. Permit shifting of equipment in order to perform alinement, servicing, tuning, removal of dust covers, and changing of tubes, while installed in aircraft.

f. Sharp bends should be eliminated in order to prevent breakage and damage to wire insulation.

6. Wires and cables attached to assemblies where relative movement occurs (such as hinges and rotating pieces; particularly control sticks, control wheels and columns, and flight control surfaces) should be installed or protected in a manner so as to prevent deterioration of the wires and cables caused by the relative movement of the assembly parts. This deterioration is caused by abrasion of one wire or cable upon the other and excessive twisting and bending. As a design objective, bundles must be installed to twist instead of bend across hinges.

Cable Lacing and Tying

Wire groups and bundles are laced or tied to provide ease of installation, maintenance, and inspection. The purpose of lacing or tying is to keep all cables neatly secured in groups and to avoid possible damage from chafing against equipment or interference with equipment operation.

Tying is the securing together of a group or bundle of wires by means of individual pieces of cord tied around the group or bundle at regular intervals. Lacing is the securing together of a group or bundle of wires inside enclosures by means of a continuous piece of cord forming loops at regular intervals around the group or bundle.

Cotton, nylon, or Fiberglas cord is used for tying or lacing. The cotton cord must be waxed to make it moisture and fungus resisting. Nylon and Fiberglas cords are in themselves moisture and fungus resisting and are not usually waxed. Pressure sensitive vinyl electrical tape is used only where the use of tape instead of cord is specifically permitted.

When lacing or tying, observe the following precautions:

1. Lace or tie bundles tight enough to prevent slipping, but not so tight that the cord cuts into or deforms the insulation. This applies especially to coaxial cable, which has a soft dielectric insulation between the inner and outer conductor.

2. Do not place ties on that part of a wire group or bundle that is located inside a conduit.

3. Lace wire groups or bundles only when they are inside enclosures, such as junction boxes. Use double cord on groups or bundles larger than 1 inch in diameter. Use single or double cord for groups or bundles 1 inch or less in diameter. (NOTE: A wire group is two or more wires tied or laced together to give identity to an individual system. A wire bundle is two or more wires or groups tied or laced together to facilitate maintenance.)

Single cord lacing (fig. 4-6 (A)) is performed as follows:

1. Start the lacing at the thick end of the wire group or bundle with a knot consisting of a clove hitch with an extra loop.

2. At regular intervals along the wire group or bundle, and at each point where a wire or wire group branches off, continue the lacing with half hitches. Space the half hitches so that the group or bundle is neat and securely held.

3. End the lacing with a knot consisting of a clove hitch with an extra loop.

4. Trim the free ends of the lacing cord to 3/8 inch minimum.

Double cord lacing (fig. 4-6 (B)) is performed as follows:

1. Start the lacing at the thick end of the wire group or bundle with a bowline on a bight.

2. At regular intervals along the wire group or bundle, and at each point where a wire group branches off, continue the lacing with half hitches, holding both cords together.

3. End the lacing with a knot consisting of a half hitch, using one cord clockwise and the other counterclockwise, and then tying the cord ends with a square knot.

4. Trim the free ends of the lacing cord to 3/8 inch minimum. The lacing of a wire group that branches off the main wire bundle is shown in figure 4-6 (C).

Tie all wire groups or bundles where supports are more than 12 inches apart. Space the ties 12 inches or less apart. (See fig. 4-7 (A).) The steps in making ties are as follows:

1. Wrap cord around wire group or bundle.

2. Make a clove hitch, followed by a square knot with an extra loop.

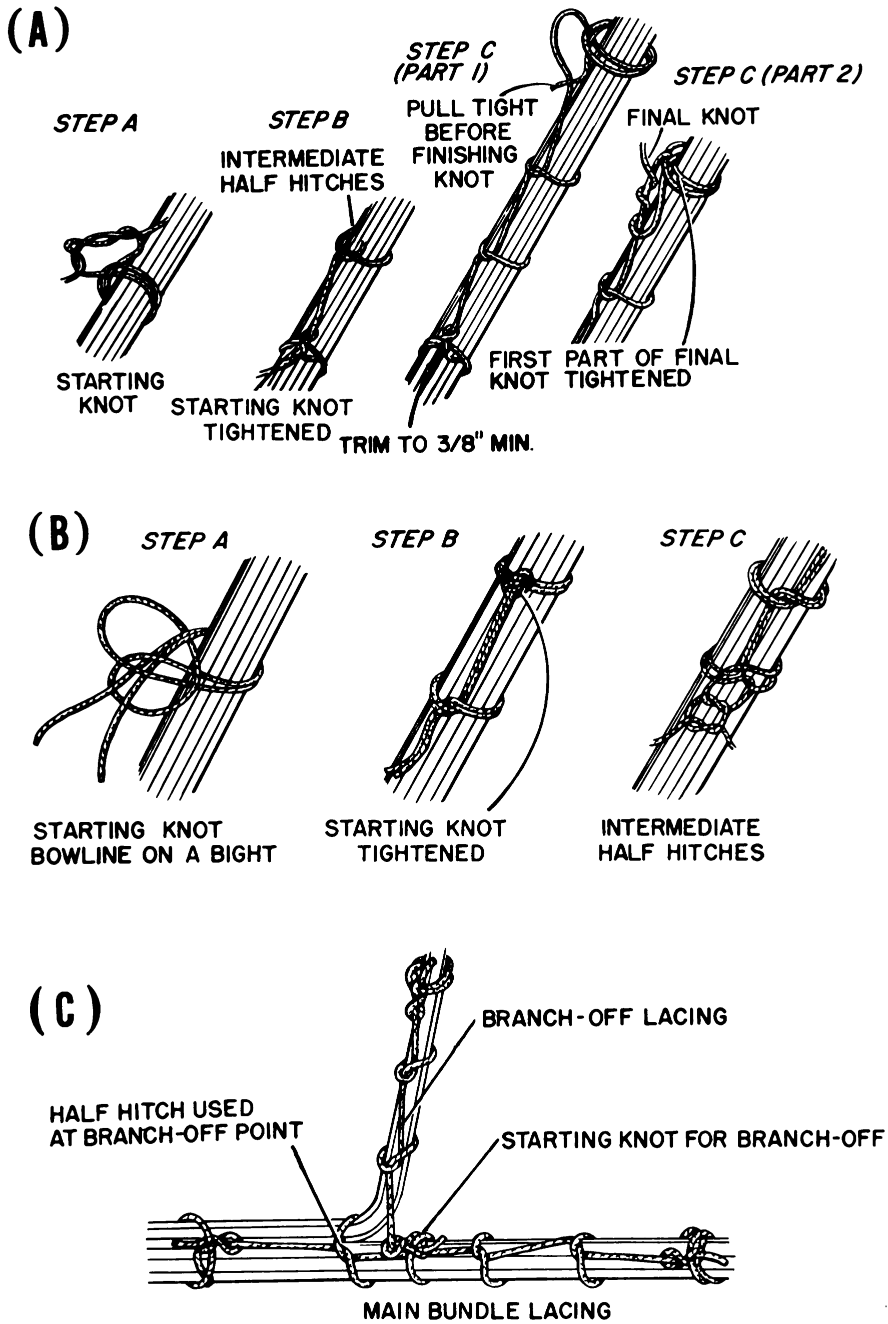


Figure 4-6.—Lacing groups or bundles.

3. Trim free ends of cord of 3/8 inch minimum. Temporary ties are used to aid in making up and installing wire groups or bundles. Use colored cord to make temporary ties, and remove such ties when the installation is complete. Cut temporary ties with scissors or diagonal pliers only. Do not use a knife or other sharp edged instrument which may damage the insulation.

In some instances groups or bundles may be secured with tape. (See fig. 4-7 (B).) When this is permissible the following method should be employed:

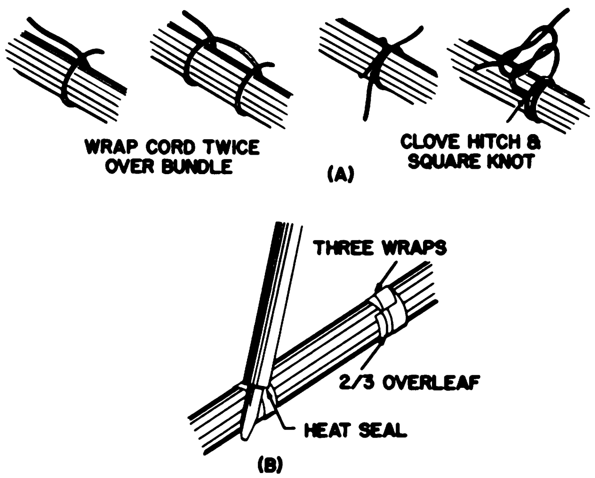


Figure 4-7.—Tying groups or bundles.

1. Wrap tape around wire group or bundle three times, with a two-thirds overlap for each turn.

2. Heat-seal the loose tape end with the side of a soldering iron heating element.

Do not use tape for securing wire groups or bundles which may require frequent maintenance.

An excellent source of additional information in connection with power distribution is NavAer 01-1A-505, Installation Practices for Aircraft Electric and Electronic Wiring. This manual presents the recommended practices and techniques to be used for installing, repairing, and maintaining aircraft electric wiring. It includes information under the following headings: Wire and cable preparation; general-purpose connectors; RF connectors and cabling; solderless terminals and splices; thermocouple wire soldering and installation; bonding and grounding; bus bar preparation; conduit fabrication; installation of bus bars, conduit, junction boxes, protective devices, and terminal strips; electrical wiring installation; lacing and typing; safety wiring; and emergency repairs.

Sleeving

Sleeving, commonly called spaghetti, has many applications in naval aviation. Some of the more common applications are to cover soldered connections, open bus bars, and permanent splices.

For general-purpose wiring, flexible vinyl sleeving, either clear or opaque, should be used. For high-temperature applications (160°F to 400°F), use silicone rubber or Fiberglas. Where resistance to synthetic hydraulic fluids or other solvents is necessary, use nylon sleeving, either clear or opaque, for best results.

Sleeving is used to help protect connections against accidental shorting and moisture, and to lengthen the arc-over path between contacts. Insulating sleeves should not be used when connections or connectors are to be moisture-proofed by potting. Also, it should not be used on some connectors that are provided with a sealing grommet which covers the soldered connection. Figure 4-8 shows an application of sleeving on a connector.

Bus bars are usually enclosed in panels or junction boxes to protect them against accidental shorting. If the bus bars are not enclosed, it may be desirable to use some protective coating. The sleeving can be used by slitting a piece of vinyl tubing and wrapping it around the bar after all connections have been made. Care should be taken to select tubing which has a large enough diameter to permit a generous overlap when it is tied in place. (See fig. 4-9 (A).)

A wire with damaged insulation may be temporarily protected by using a sleeve of flexible tubing 1 1/2 times the outside diameter of the wire. The length should be at least 2 inches longer than the damaged portion of the insulation. Split the sleeve lengthwise and wrap it around the wire at the damaged section, and

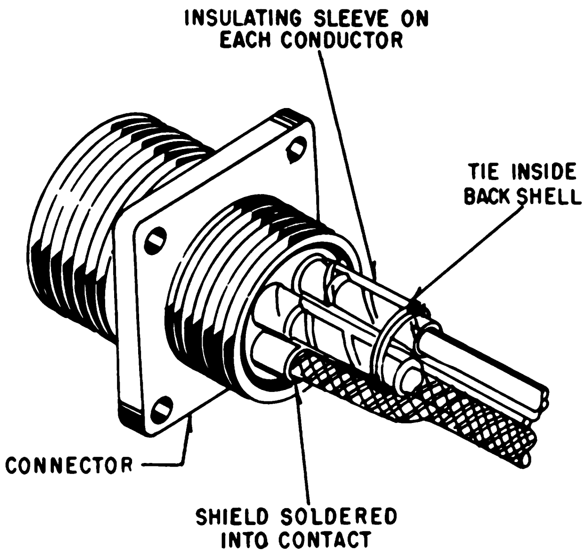


Figure 4-8.—Application of sleeving on a connector.

then tie with nylon braid at each end and at 1-inch intervals over the entire length. (See fig. 4-9 (B).) Since the replacement of damaged wire, by use of permanent splices if necessary, is the only satisfactory repair, the procedure just described should be performed only in case of emergency.

To cover a permanent splice, as shown in figure 4-9 (C), the sleeving is slipped on the wire before the splicing operation. After the splice is completed, it is moved to cover the finished splice and then tied at each end with nylon braid.

A slightly different arrangement is used for the repair of shielded wire. In this application note that two pieces of sleeving are used, one for the braid and one for the wire itself. This is shown in figure 4-9 (D).

When marking tubing (sleeving), the same procedure is used as when marking wire. After the first mark, the remaining sleeve is marked at intervals that will leave about 1 inch between marks. Rotate the sleeving at each marking to cause the marks to be on opposite sides. Figure 4-10 shows a marking machine used to mark wire as well as sleeving. The operating instructions provided with the machine should be followed to

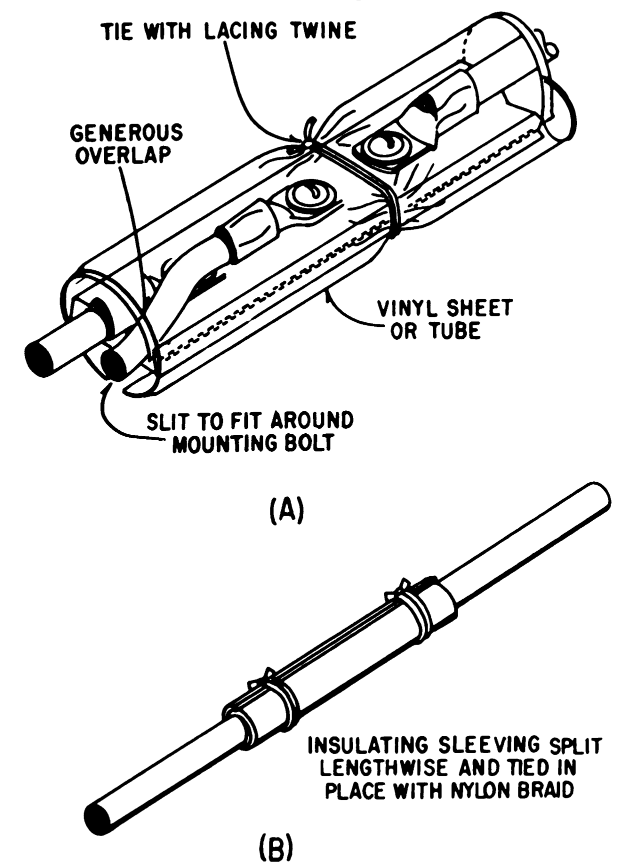


Figure 4-9.—(A) Vinyl tubing around bus bar; (B) insulation repair with sleeving.

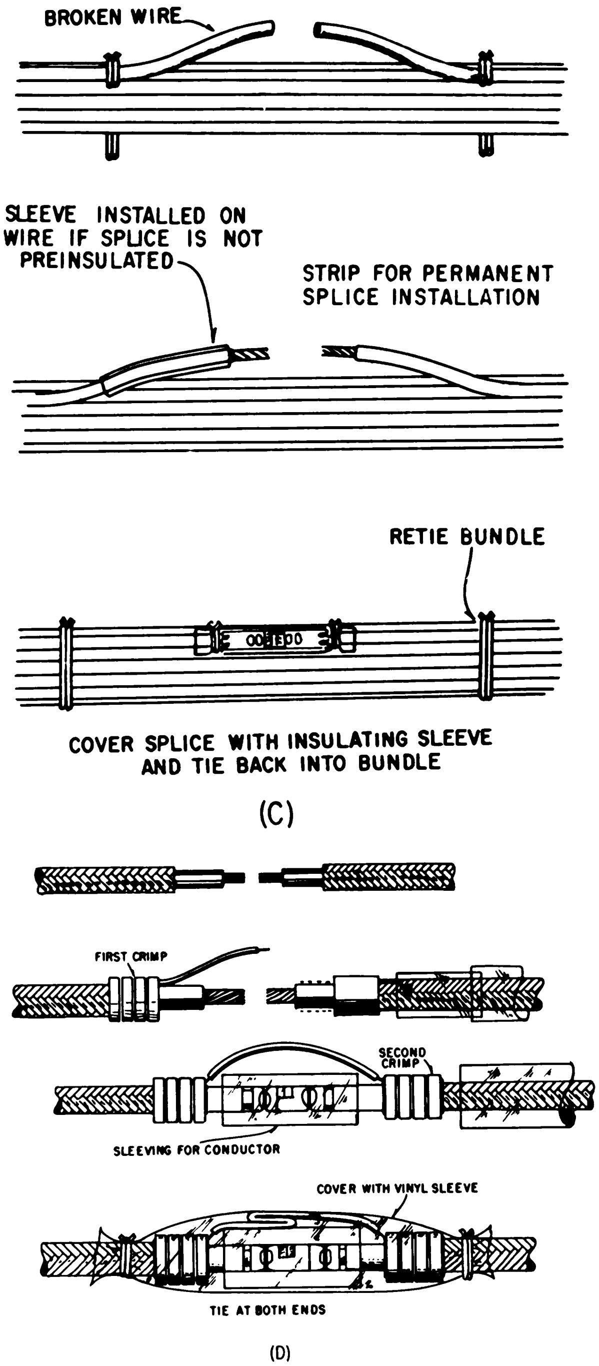


Figure 4-9.—(C) Permanent splice repair; (D) repair of shielded wire.

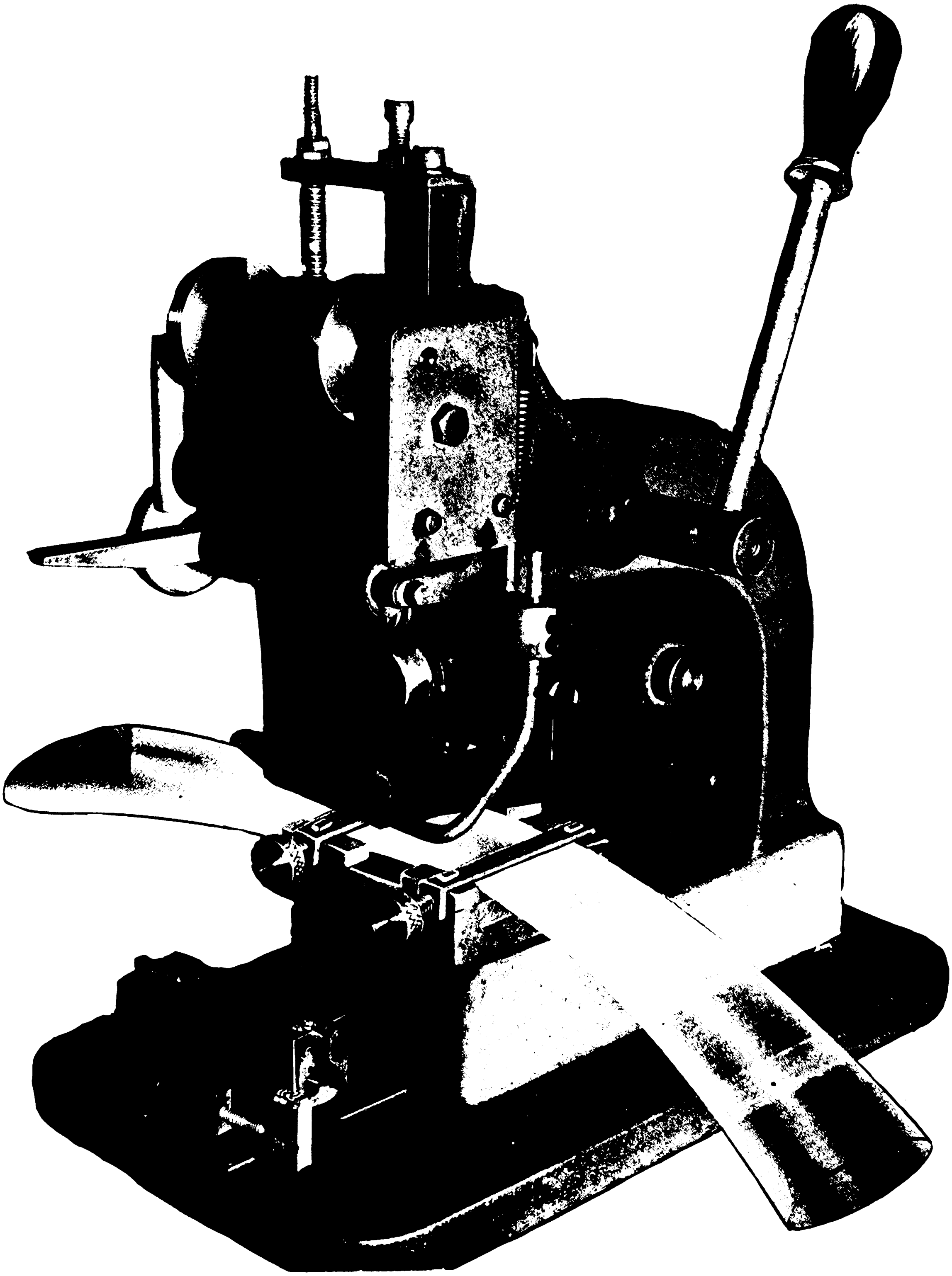


Figure 4-10.—Marking machine for sleeving.

Table 4-3.—Wire and sleeving sizes.

Wire Sizes		Sleeving sizes	
Copper (AN)	Aluminum (AL)	Sleeving No.	Sleevin ID (inc
24		12	0.08
22		11	0.09
20		10	0.10
18		9	0.11
16		8	0.11
14		7	0.14
12		6	0.16
10		4	0.20
8	8	2	0.26
6	6	0	0.33
4	4	3/8 inch	0.37
2	2	1/2 inch	0.50
1	1	1/2 inch	0.50
0	0	5/8 inch	0.62
00	00	5/8 inch	0.62
000	000	3/4 inch	0.75
0000	0000	3/4 inch	0.75

insure clear letters or numbers. Table 4-3 is a guide that may be used to aid in determining the proper size sleeve for the wire to be covered.

OPERATION AND CONSTRUCTION OF SWITCHES

A switch may be described as a device used in an electrical circuit for making, breaking, or changing connections under conditions for which the switch is rated. Switches are rated in amperes and volts; the rating refers to the maximum voltage and current of the circuit in which the switch is to be used. Because it is placed in series, all the circuit current will pass through the switch. Because it opens the circuit, the applied voltage will appear across the switch in the open circuit position. Switch contacts should be opened and closed quickly to minimize arcing; therefore, switches normally utilize a snap action.

Many types and classifications of switches have been developed. A common designation is by the number of poles, throws, and positions they have. The number of poles indicates the number of terminals at which current can enter the switch. The throw of a switch signifies the number of circuits each blade or contactor can complete through the switch. The number of tions indicates the number of places at whi operating device (toggle, plunger, etc.) will to rest. Figure 4-11 presents the schemati grams of some often used switches.

An example of the switch position de tion is a toggle switch which comes to r either of two positions, opening the circ one position and completing it in another is called a two-position switch. A toggle s which is spring loaded to the OFF positi must be held in the ON position to comple circuit is called a momentary contact position switch. If the toggle switch will to rest at any of three positions, it is ca three-position switch.

Another means of classifying switches method of actuation; that is, toggle, pushb sensitive, and rotary types. Further class tion can be accomplished by a descript switch action such as on-off, momentary c on-momentary off, etc. Momentary c switches hold a circuit closed or open o long as the operator deflects the act control.

MANUALLY OPERATED SWITCHES

One of the most common types of ai switches is the toggle. Toggle switches

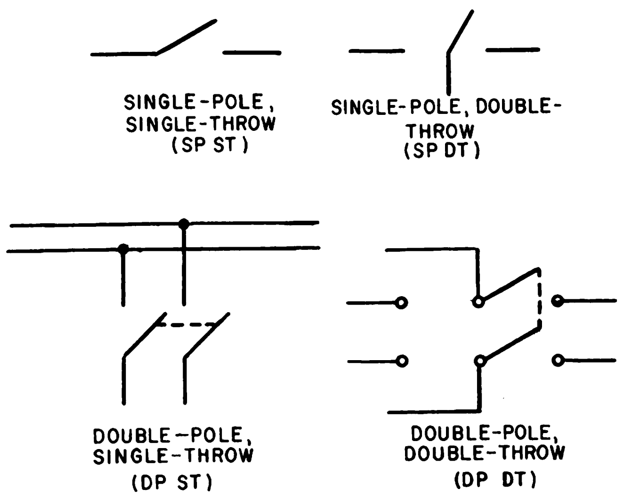


Figure 4-11.—Schematic diagrams of commonly used switches.

their moving parts enclosed. A double-pole, double-throw, ON-OFF-ON toggle switch is shown in figure 4-12. These switches have many uses and are used especially for applying power to various circuits. They are often provided with a luminous tip on the lever so as to be visible in the dark.

Pushbutton switches have one or more stationary contacts and one or more movable contacts. The movable contacts are attached to the pushbutton by an insulator. This switch is usually spring loaded and is of the momentary contact type. These switches have many uses, such as indicator light checks and circuit reset. Occasionally you will find the push-on and push-off type of switch, but these are not common in naval aviation.

A rotary selector switch may perform the functions of a number of switches. As the knob of a rotary selector switch is rotated, it opens one circuit and closes another. This can be seen from an examination of figure 4-13. Some rotary switches have several layers of wafers. By adding wafers, the switch can be made to operate as a large number of switches. Ignition switches and voltmeter selector switches are typical examples of this type.

MECHANICALLY OPERATED SWITCHES

Mechanically operated switches are used for such purposes as landing-gear position indication, bomb-bay door position indication, motor-drive limit switches, and the howler signal in connection with landing gear and folding wings. Many of these are the sensitive, snap-acting switches found in all aircraft. They are widely used because of their small size, light weight, and excellent dependability. The term Micro switch, although frequently used in referring to all switches of this type, is a trade name for the switches made by the Micro Switch Division of the Minneapolis Honeywell Regulator Company.

These switches will open or close a circuit with a very small movement of the tripping device (1/16 inch or less). They are usually of the pushbutton variety and usually depend upon one or more springs for their snap action. For example, the heart of the Micro switch is a beryllium copper spring, heat-treated for long life and unfailing action. The simplicity of the one-piece spring contributes to the long life and dependability of this switch. The basic Micro switch is shown in figure 4-14.

The versatility of the snap-action switch is shown in figure 4-15, which shows how the basic switch may be used with different type enclosures and actuators. The particular type

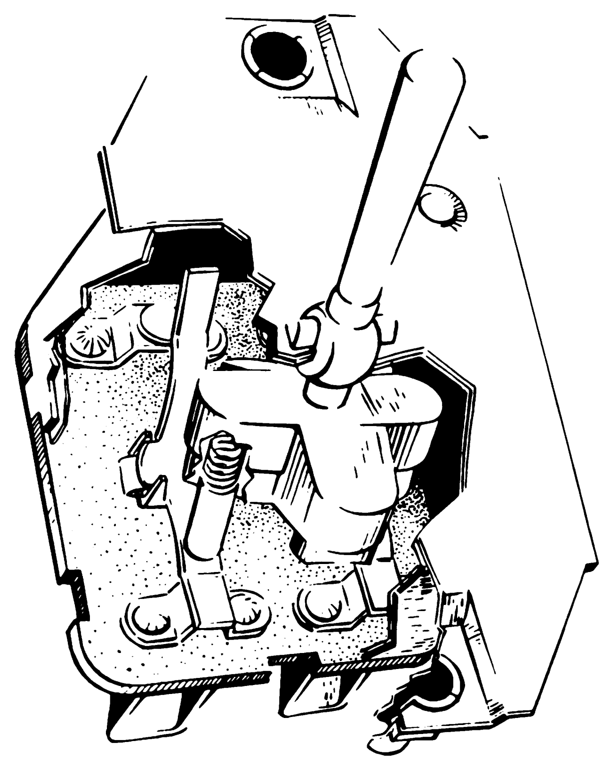


Figure 4-12.—Toggle switch.

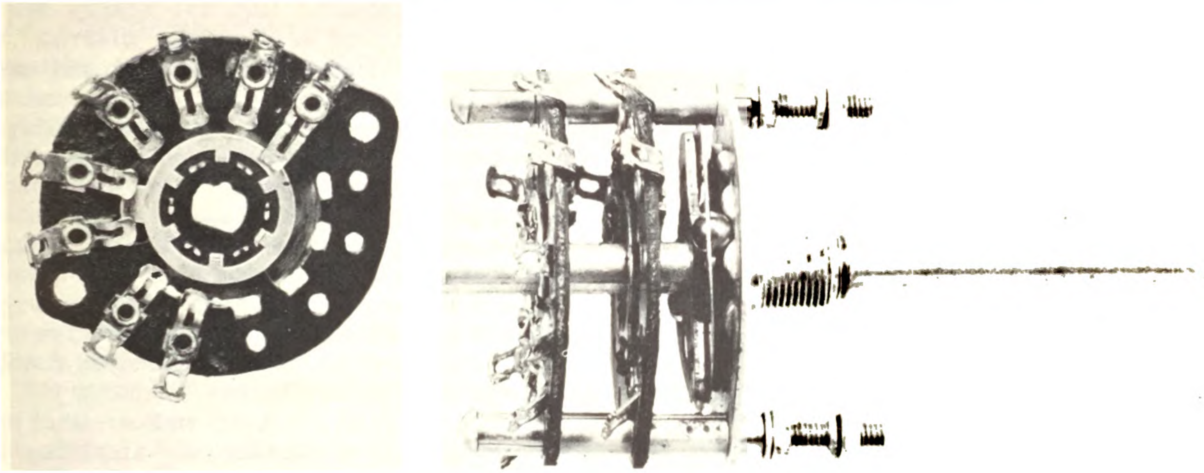


Figure 4-13.—Rotary selector switch.

switching unit used depends upon the function it is to perform and environmental conditions. Figure 4-15 (A) shows a lightweight aluminum enclosure which may contain one or more plastic enclosed basic switches. The plastic enclosure provides electrical insulation between the housing and the energized electrical parts, support for the terminals, and a dusttight box around the electrical contacts.

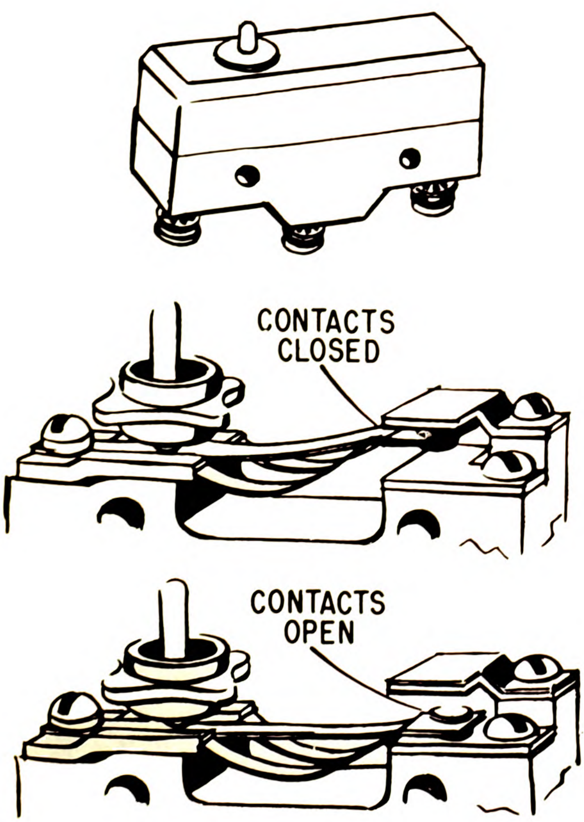


Figure 4-14.—Micro switch.

Figure 4-15 (B) shows one of the various types of switch actuators that may be used with basic switches when complete enclosures are not needed. They provide protection and mounting means. They relay the operating motion from a cam or slide to the basic switch in a way that assures long life and dependability. Figure 4-15 (C) shows a toggle type switch which uses one or more of the basic subminiature switches. These subminiature switches are smaller than the conventional Micro switch and are finding wide use in various switching arrangements.

Pressure-operated switches usually have Bourdon tubes, syphons, or diaphrams against which the fluids or air operate to actuate the switch. Some uses of pressure switches are in connection with fuel, oil, and hydraulic pressure signals and electric heaters.

Thermal switches usually incorporate a bimetallic sheet that bends or snaps at a desired temperature to actuate the switch. They are used extensively as circuit breakers and also find application in controlling the igniter circuit on heater and operating signal lights at critical temperatures.

MAINTENANCE OF SWITCHES

While the switch itself is relatively simple to check, it sometimes offers difficulty in maintenance because of its location in inaccessible

places. After a visual inspection of the connections and the switch, a continuity test will indicate any malfunctions. When the switch mechanism is found to be defective, it normally is not repairable and therefore should be replaced.

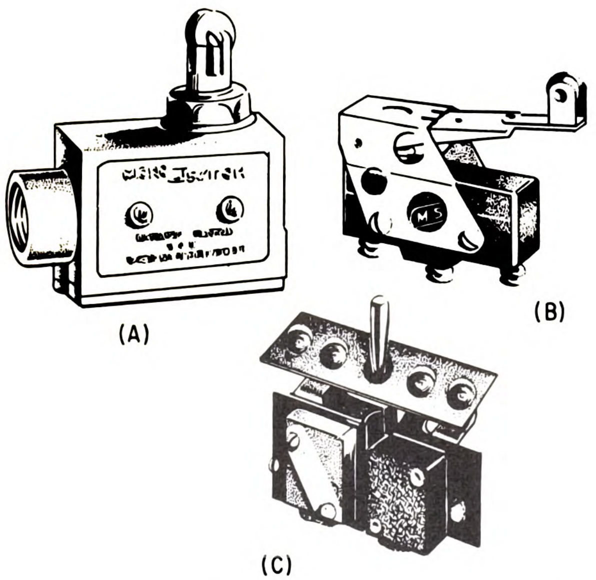


Figure 4-15.—Snap-action switching units.

When enclosed switches are used, failure to seal properly around cable openings may cause difficulty. Altitude changes permit "breathing" of moist air into enclosures with improperly sealed cable openings, and the moisture in the air may condense within the switch enclosure. The condensation can short across the switch terminals and can corrode the switch actuators in a manner that may make them inoperative. This difficulty can be corrected by careful sealing of openings or by using hermetically sealed switches. Hermetically sealed switches will also prevent dust and dirt from reaching the contacts and thereby reduce the possibility of high resistance and open circuits.

Some switches are damaged during installation, particularly those with plastic housings. Proper care in installing or replacing plastic enclosed switches will eliminate this.

Some switch assemblies are equipped with adjustments which enable them to operate at a preset time or pressure. Caution should be exercised in making these adjustments; if they are not accurate, damage can result.

RELAYS

Relays are electrically operated switches that are classified according to their use as control relays, power relays, or sensing relays. The power relays are the workhorses of the aircraft's electrical system. As such, they control the heavy power circuits.

The function of a control relay is to take a relatively small amount of electrical power and use it either to signal or to control a large amount of power. Where multipole relays are used, several circuits may be controlled simultaneously.

The control relays may act in somewhat the same capacity as a vacuum tube amplifier in an electric circuit. While the vacuum tube is ordinarily used to amplify voltage, the relay usually amplifies current or power. The use of relays saves space and weight in the aircraft by permitting the use of small switches at remote control stations. These switches permit the operator to control large amounts of current at other locations in the aircraft, and the heavy power cables need to be run only to the point of use. Only lightweight control wires are connected to the control switches. Safety is also an important factor in using relays, since high power circuits can be switched remotely without danger to the operator.

Control relays, as their name implies, are frequently used in the control of other relays, although the small control relays find many other uses. With these, electron tube plate currents can control the larger currents necessary to operate electrical devices. They find frequent use in automatic relaying circuits, where a small electric signal sets off a chain reaction of successively acting relays performing various functions. Control relays can also be used in so-called "lockout" action to prevent certain functions, such as gunfiring, from occurring at the improper time. Various electrical operations in the equipment which must not occur simultaneously can be "interlocked" by control relays. Another important function of control relays in aircraft equipment is for "sensing." Control relays are used for sensing undervoltage and overvoltage, reversal of current, and excessive currents.

Another possible classification of relays is open, semisealed, and sealed. Semisealed relays have protective covers and are gasketed against entrance of salt, dust, and foreign material into the contact or mechanism area.

These relays are still considered satisfactory for certain applications in current aircraft. Open relays are seldom used outside of black boxes.

For other applications in today's aircraft, however, it is necessary to go beyond the protection offered by the open type and the semisealed relays. When such relays are used, quick changes in altitude, humidity, and temperature can cause condensation of water vapor within the unit. Subsequent low temperature will then freeze the moisture on the contactor with a resultant inability to carry electric current.

Hermetically sealed relays were developed to answer the demands of current aircraft equipment. A true hermetic seal is generally considered one that is metal to metal or glass to metal. Plastic or plastic rubber type gasketed seals are not generally considered true hermetic seals. However, both semisealed and hermetically sealed relays are used. There are applications where a gasket type sealed relay may be adequate, but the true hermetically sealed type is generally considered to be more permanent. Besides being independent of altitude changes, the hermetically sealed relay also has the advantage of being protected from improper adjustments.

In general, the basic components of a relay are as follows: The coil or solenoid, the iron core, the fixed and movable contacts, and the mounting (and if sealed, the can). A manual switch, limit switch, or other small control device starts and stops the flow of current to the magnet coil. The flow of electric current through the coil creates a strong magnetic field around and within the coil. This magnetic field moves a clapper or plunger which completes the magnetic circuit. Figure 4-16 (A) shows a basic single coil clapper type relay. The dashed lines indicate the magnetic lines of flux. For a more complete analysis of the theory of operation see Basic Electricity, NavPers 10086-A.

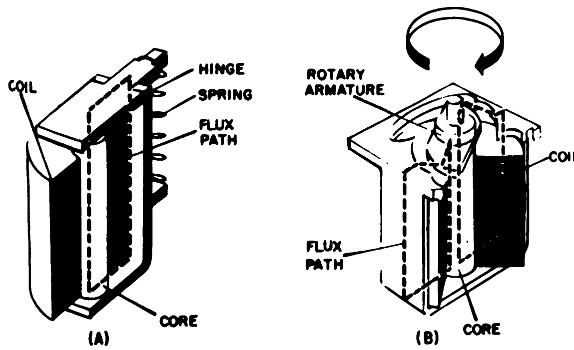


Figure 4-16.—Basic types of relays.

The second basic type of relay is the rotary. (See fig. 4-16 (B).) Although this type of construction is not as common as the clapper type, the rotary type has greater vibration and shock resistance than the others. The disadvantage is that they are somewhat sluggish and require higher operating power for many purposes. The rotary relay operates on the principle of an electric motor, but through only a small arc. The problem of hanging contacts on such a mechanism is a difficult one, and therefore the use of these devices is limited to applications where high shock warrants the larger size and weight. When used with standard wafer switch assemblies, this type of relay provides a means for assembling a switching device of any degree of complexity.

Occasionally you will encounter relays operating from an a-c supply. These a-c relays depend upon the same fundamental principles as the d-c relay; that is, magnetic fields. When a.c. is applied to an electromagnet, the current will pass through zero twice every cycle. Since the pull on the armature is proportional to the current through the electromagnet, the armature tends to open every time the current nears zero, causing chatter. To remedy this, shading coils (sometimes called shaded poles) are used.

A shading coil consists of copper band or stamping which is short-circuited and embedded around part of the electromagnet pole face. By being placed around part of the pole face, it acts as a shorted transformer secondary. The current in the main coil lags the applied voltage by approximately 90°, and the flux is in phase with the current. The voltage of the shading coil is induced voltage and lags the current in the main coil by 90°. Since the shading coil acts like a shorted secondary (resistive), the current in the shading coil is in phase with the induced voltage. Therefore, the magnetic field of the shading coil lags the magnetic field of the main coil by 90°. This means that flux will exist in the electromagnet even when the main coil current becomes zero. Thus, chattering is prevented.

The arrangements of relay contacts are found in many different forms. Usually the number and sequence of switching operations to be performed dictates the contact arrangement.

It is often desirable to introduce time delays by use of relays. One method is to use a thermal relay for a time delay. The operation of this type of relay is very similar to the thermal circuit breaker (discussed later in this chapter) with the exception that it closes the circuit rather than opens it, when heated. Due to the simple mechanism, it can be made very small and hermetically sealed, making it ideal for use in aircraft. Because the thermal relay is activated by heat, it can be used on either a.c. or d.c.

Maintenance of Relays

The relay is one of the most dependable electromechanical devices in use, but like any other mechanical or electrical device in aircraft equipment, relays occasionally wear out or become inoperative for one reason or another. Should relay inspection determine that a relay has exceeded its safe life, the relay should be removed immediately and replaced with another of the same type. Care should be exercised in obtaining the same type replacement because relays are rated in voltage, amperage, type of service, number of contacts, continuous or intermittent duty, and similar characteristics.

For spotting potential relay trouble during preventive maintenance, the following guides are suggested: Check for charred or burned insulation on the relay and for darkened or charred terminal leads coming from the relay. Both of these indicate overheating. If there is even a slight indication that the relay has overheated, it should be replaced with a new relay of the same type. An occasional cause of relay trouble is not the fault of the relay at all, but is due to overheating caused by the power terminal connectors not being tight enough. This should always be checked during preventive maintenance.

It is recommended that covers not be removed from semisealed relays in the field. Removal of a cover in the field, although it might give useful information to a trained eye, may result in entry of dust or other foreign material which may cause contact discontinuity. What is even more serious is that removal of the cover may result in loss of or damage to the cover gasket. This will increase the possibility of an explosion.

ELECTRICAL CONNECTORS

In the discussion which follows, the word "connector" is used in a general sense. It applies equally well to connectors designated by "AN" numbers and those designated by "MS" numbers. AN numbers were formerly used for all supply items cataloged jointly by the Army and Navy. Many items, especially those of older design, continue to carry the AN designator, even though the supply system is shifting over to MS (Military Specification) numbers.

AN specification numbers for connectors have been generally superseded by MS numbers. However, in many instances, connectors are still referred to as "AN connectors."

Connectors are devices attached to the ends of cables and sets of wires to make them easier to connect and disconnect. Connectors consist of two portions—the fixed portion, called the receptacle; and the movable portion, called the plug. Plug assemblies may be of the straight type or the 90° type, while receptacle assemblies may be the wall-mounting, box-mounting, and integral-mounting types. MS specification numbers and letters identify the type, style, and arrangement of a connector.

Electrical connectors are designed to provide a detachable means of coupling between major components of electrical and electronic equipment. These connectors are constructed to withstand the extreme operating conditions imposed by airborne service. They must make and hold electrical contact without excessive voltage drop despite extreme vibration, rapid shifts in temperature, and great changes in altitude.

These connectors vary widely in design and application. Each connector consists of a plug assembly and a receptacle assembly. The two assemblies are coupled by means of a coupling nut, and each consists of an aluminum shell containing an insulating insert which holds the current-carrying contacts. The plug is usually attached to a cable end and is the part of the connector on which the coupling nut is mounted. The receptacle is the half of the connector to which the plug is connected an is usually mounted on a part of the equipment.

There are wide variations in shell type, design, size, layout of contacts, and style of insert. Six types of connector shells are shown in figure 4-17.

Connector MS 3100 is a wall-mounting receptacle. It is intended for use with conduit to eliminate the necessity of installing conduit boxes.

Connector MS 3101 is a cable-connecting receptacle, and is used with cable or in other

installations where mounting provisions are not required.

MS 3102 is a box-mounting receptacle, and is intended for use where a detachable connection is required on a shielded box or unit of equipment.

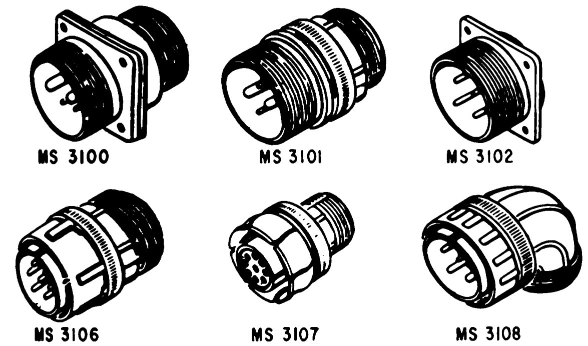


Figure 4-17.—Connector shells.

MS 3106 is a straight plug which is used when circuits are to be connected where space limitations are not critical. It consists of a front shell (usually referred to as an "insert barrel"), a coupling ring, the insert, an insert retaining device, and a rear shell.

MS 3107, a quick-disconnect plug, is u where very rapid disconnections must be ma A special coupling device is used instead coupling ring; otherwise it is similar to MS 31

MS 3108, a 90° angle plug, is similar construction to MS 3106 except that the r shell provides a right angle bend which is quired where space is limited.

The shells of MS connectors are made eight types, each for a particular kind of ap cation. A letter designation is used in the number to indicate the shell design, as in 3106E, where E is the shell type indicator. shell indicators are as follows:

A—Solid shell.
B—Split shell.
C—Pressurized type.
D—Sealed construction.
E—Environment resistant.
F—Vibration resistant.
H—Flame barrier shell.
K—Fireproof construction.

Solid shell connectors are used where special requirements, such as fireproofing moistureproofing, must be met. The rear sh are made from a single piece of alumin

Split shell connectors allow maximum cessibility to soldered connections. The r shell is made in two halves, either of which be removed. Figure 4-18 shows an exploded v of one type of a split-shell connector.

Pressurized connectors provide a pressu tight feed-through for wires that pass thro walls or bulkheads of pressurized compartme in high-altitude aircraft. The contacts

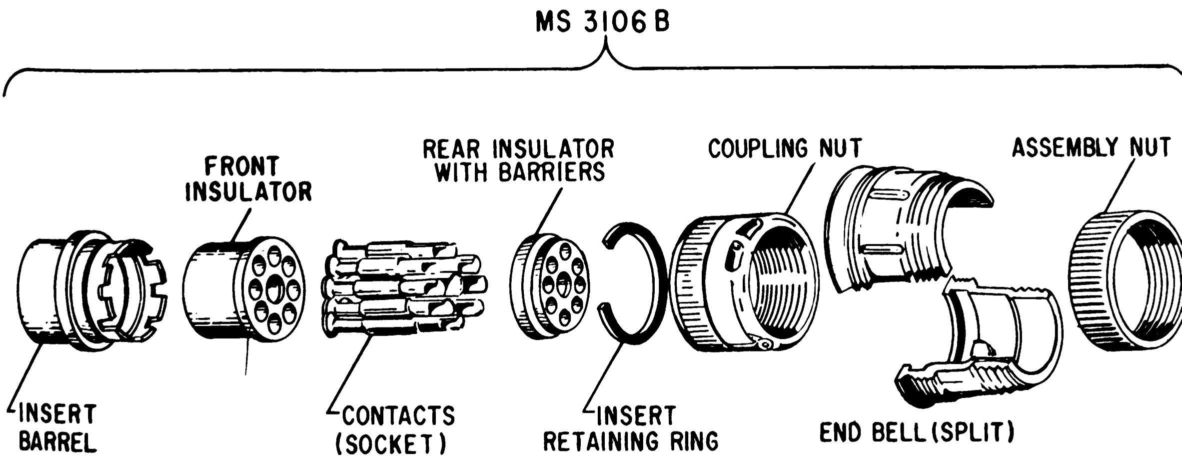


Figure 4-18.—Exploded view of a split-shell connector.

usually molded into the insulator, and the shell is spun over the assembly to seal the bond.

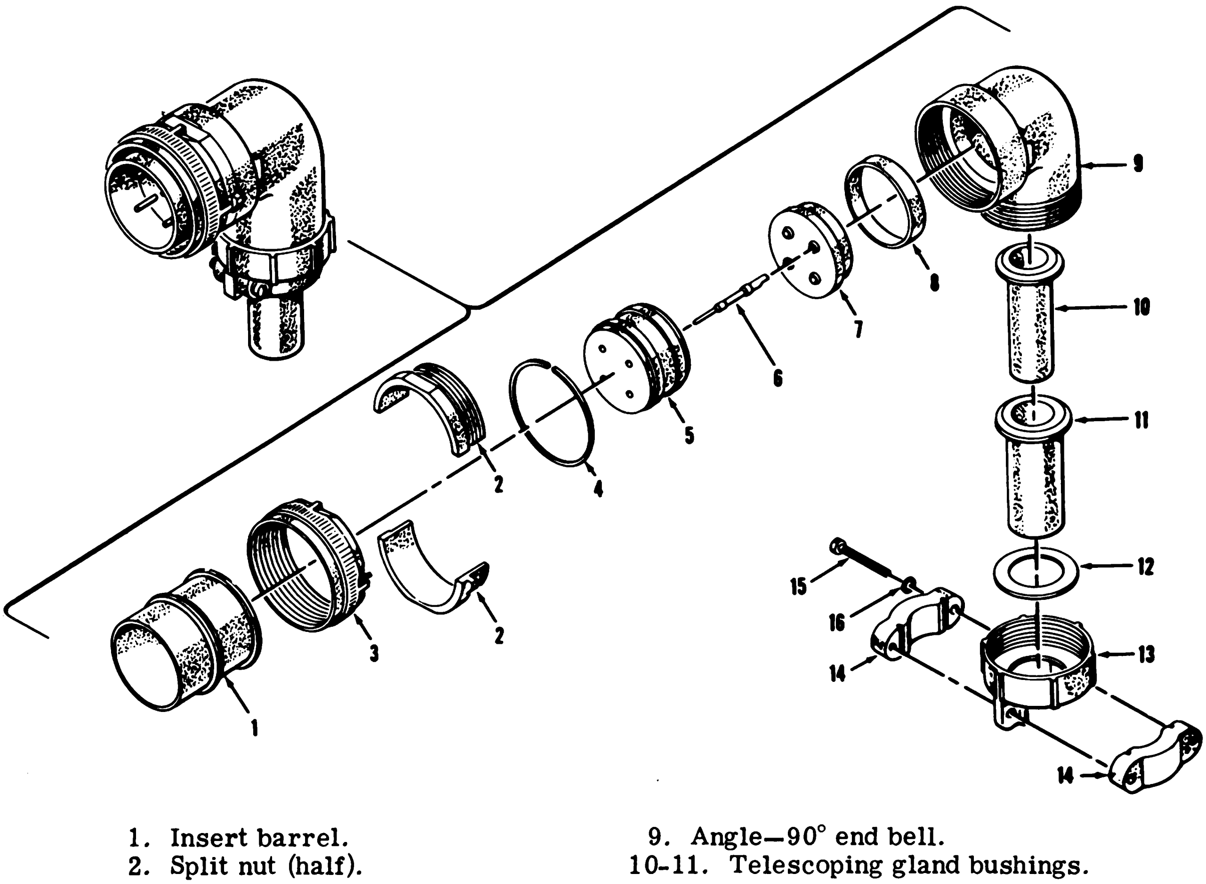
Sealed connectors are employed in equipment that is sealed and operated under gas pressure. These connectors include a glass-to-metal seal and have either special rubber inserts or a cementing compound applied to the insert.

Vibration-resistant connectors are designed for use in equipment that is subjected to intense vibrations in installations on or near reciprocating engines.

Fireproof connectors are made under specifications which require that the connector maintain effective electrical service for a limited time even when exposed to fire. The inserts are made of a ceramic material, and special crimp type contacts are used.

Moisture-resistant connectors consist of a combination of the features of the solid shell, the pressurized, and the vibration-resistant types. The component parts of this kind of connector are shown in figure 4-19.

Each connector is given an identification symbol which is called the MS part number. This symbol indicates the shell type, the shell design, the size, the insert type, the insert style, and the insert position. An example is the designator—MS 3100-A-16-11 PX.



1. Insert barrel.
2. Split nut (half).
3. Coupling nut.
4. Split-nut retaining ring.
5. Insulator.
6. Contact (pin).
7. Grommet.
8. Ferrule.

9. Angle—90° end bell.
10-11. Telescoping gland bushings.
12. Bushing washers.
13. Gland-clamp fittings.
14. Clamp saddles.
15. Clamp-saddle screws.
16. Lockwashers.

Figure 4-19.—Exploded view of a 90° angle connector.

The letters MS form the prefix. The number 3100 indicates the shell type and identifies the connector as one of the types shown in figure 4-17.

The letter A indicates a solid shell connector. The number 16 is the shell size.

The number 11 is a designation of the insert pin arrangement used in the connector. A chart showing various pin arrangements may be found in the Operation and Service Instructions Manual, AN Electrical Connectors (AN-03-5-90).

The letter P means that the insert is a pin, or male, insert. (The letter S is used to indicate a socket, or female, insert.)

The concluding letter, X, is a designation of the insert position. Connectors specially designed for a particular application sometimes have nonstandard contact, or insert, positions. Four positions of the inserts are employed, and these are called W, X, Y, and Z. Each letter refers to an angle by which the insert is rotated from the standard position. When the standard position is employed, no letter is shown at the end of the MS designation.

Three common types of subminiature connectors are shown in figure 4-20. Since these connectors are the wire-connected type, they have no flanges for mounting. However, the receptacle shown in part (C) can be mounted with nuts and lockwashers. They are used on miniature instruments, switches, transformers, amplifiers, and relays.

The subminiature connectors described and shown in figure 4-20 have not proven sufficiently satisfactory and are not being used in new aircraft designs. Their use is limited to those aircraft in which they were initially installed.

The new miniature connectors (MS 311X and 313X series) are intended to supersede these subminiature connectors. The new miniature connectors differ from the types just described in their method of coupling and contact sizes. Two types of quick-disconnect couplings are provided—axial and bayonet.

Through a reduction in size of contacts, from 0.062- to 0.040-inch diameter, a greater number of contacts per unit area can be achieved. The miniature connectors with smaller contacts rated at 7.5 amperes have found increased use through the advent of a-c power in aircraft, where the majority of the circuits are low power and low current. All these connectors are environment resisting Class E, and are provided in the same plug and receptacle styles as the AN types. Hermetic receptacles and connectors suitable for potting are also provided in this series.

Coaxial connectors may be divided into seven series (BNC, N, C, HN, LC, pulse, and twin). Figure 4-21 shows all except the LC and twin types.

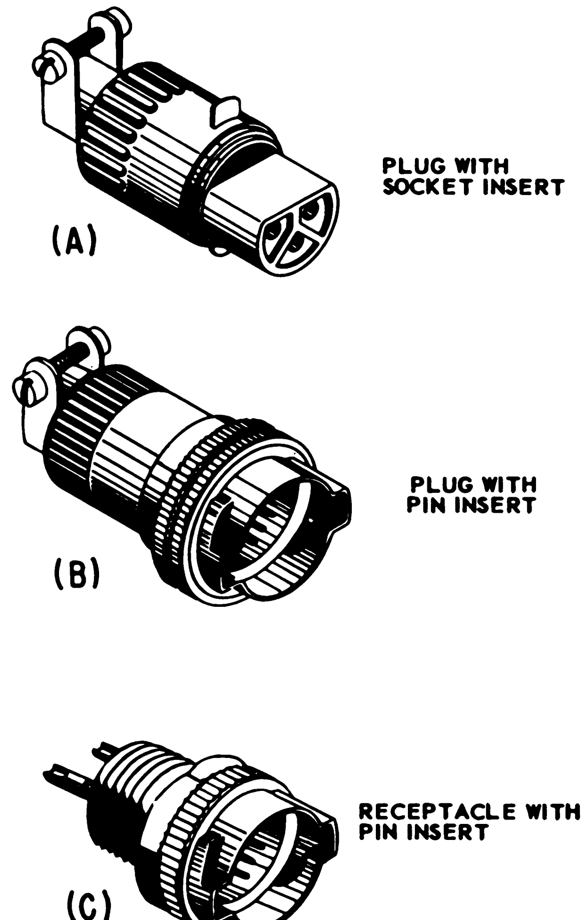


Figure 4-20.—Subminiature connectors.

Each series consists of plugs, panel jacks, receptacles, and straight and right angle adapters. The BNC series (fig. 4-22) are small, lightweight, quick-connect, and quick-disconnect type connectors used with small coaxial cables such as those used for carrying video or low frequency signals. The N series are the general-purpose screw-lock connectors. These are used primarily in RF applications. The C types are similar to the N series in that they are used with medium sized cables but have the quick-disconnect feature. HN types are high voltage-connectors for use with medium sized cables

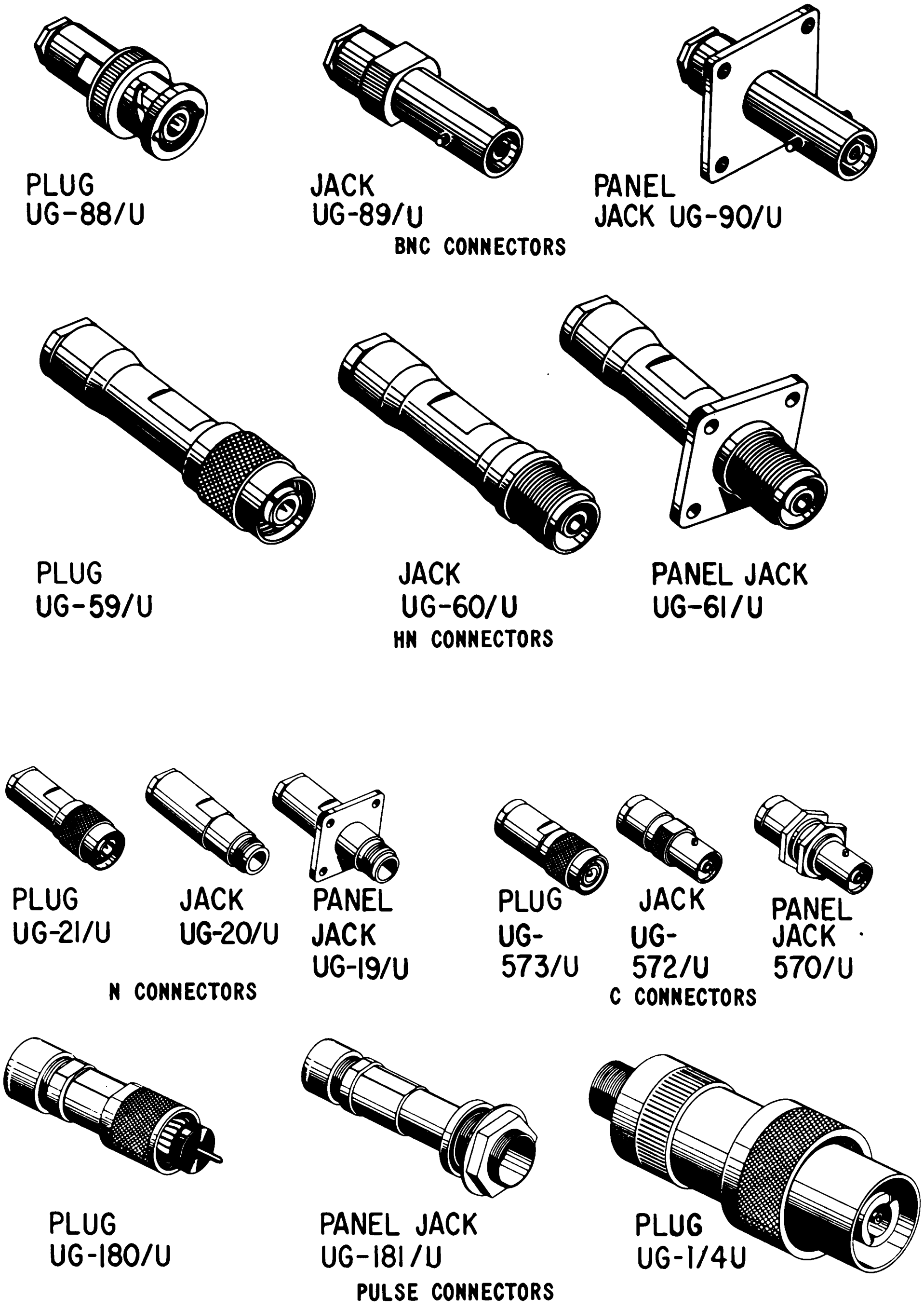


Figure 4-21.—Several typical coaxial connectors.

such as transmitter to antenna connections, while the LC series are large connectors. The pulse series are widely used in naval aircraft equipment. They are used with high voltage pulse cables. The twin series are used with cables that carry UHF frequencies and are sometimes called UHF connectors.

Frequently it may be necessary for the AE to fabricate a cable using connectors. The type of connector to be used is specified in the

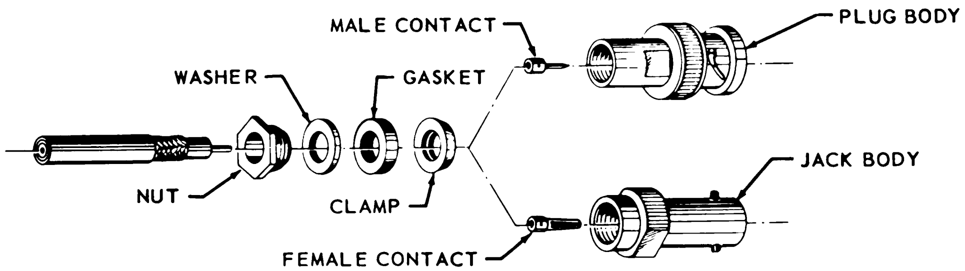


Figure 4-22.—Exploded view of a standard BNC connector.

Maintenance Instructions Manual for the particular aircraft. The following is an outline of the procedure for fabricating a cable:

1. Disassemble the connector to allow access to the terminals and devise a means of holding the connector so that both hands are free.
2. Cut cables to the correct length.
3. Strip the wire end with a wire stripper or knife. If a knife is used, avoid cutting or nicking the wire strands. Tin the bar wire end.
4. Run the wires through the connector assembly and coupling nuts.
5. See that all surfaces are clean.
6. Flow rosin-core solder into the connector terminals. Insert the wire into the terminals, holding the tip of the soldering iron against it. As the solder melts, push the wire into the cavity. Hold the wire steady while the solder cools. Care should be taken to avoid injuring the connector insulation with the soldering iron. When soldering the connector, follow a prearranged sequence. The recommended sequence is to start from the bottom connection and work from left to right, moving up a row at a time. After soldering the connections, the shields, if used, are soldered to a common terminal on a ferrule. The cable is then laced and the connector reassembled and moistureproofed if necessary.

Fabricating instructions are contained in NavAer 01-1A-505, Handbook of Installation Practices for Aircraft Electrical and Electronic Wiring.

Detailed information for selecting the proper connector as well as complete installation instructions may be found in AN 03-5-90.

MOISTUREPROOFING

Present Navy practice is to use E, R, or potted connectors (moistureproof or environmentproof connectors). However, operating conditions sometimes demand that ordinary electrical connections on older types of aircraft be given a moistureproofing treatment. The basis of moistureproofing is the application of a sealing compound.

Moistureproofing reduces failure of electrical connectors and reinforces the wires at the connectors against failure caused by vibration and lateral pressure, both of which fatigue the wire at the solder cup.

The sealing compound also protects electric connectors from corrosion and contamination by excluding metallic particles, moisture, and aircraft liquids. As a result of its improved dielectric characteristics, it reduces the possibility of arc-over between pins at the back of electric connectors.

The sealant is provided in kit form through the normal supply channels. Sealing (or potting as it is called) is not required on environment-proof E connectors or connectors located in areas where the temperature exceeds 200° F. The sealing compound deteriorates after long exposure to ambient temperatures above 200° F.

The detailed instructions for performing sealing operations may be obtained from the Electronic Material Change 89-55. A summary of the procedures involved in sealing a connector is as follows:

1. Prepare a used connector by removing existing sealants and cleaning. The cleaning solvent used must clean thoroughly, evaporate quickly, and leave no residue. Remove all sleeving from the wires. Resolder loose or poorly soldered connections and add a length of wire approximately 9 inches long to each unused pin. Remove any excess rosin from around the pins and the insert; a stiff bristle brush is helpful in doing this. Now repeat the cleaning; and separate the wires evenly.

In preparing a new connector, solder wiring to the connector pins as required for the intended

use and, in addition, the spare wires as just described. Next, remove the excess rosin, clean and spread the wire.

2. Thoroughly mix the accelerator and base compound. The ratio of the amount of accelerator-to-base compound is critical; therefore, the entire quantity of accelerator furnished must be added to the base compound (See fig. 4-23 (A) and (B).)

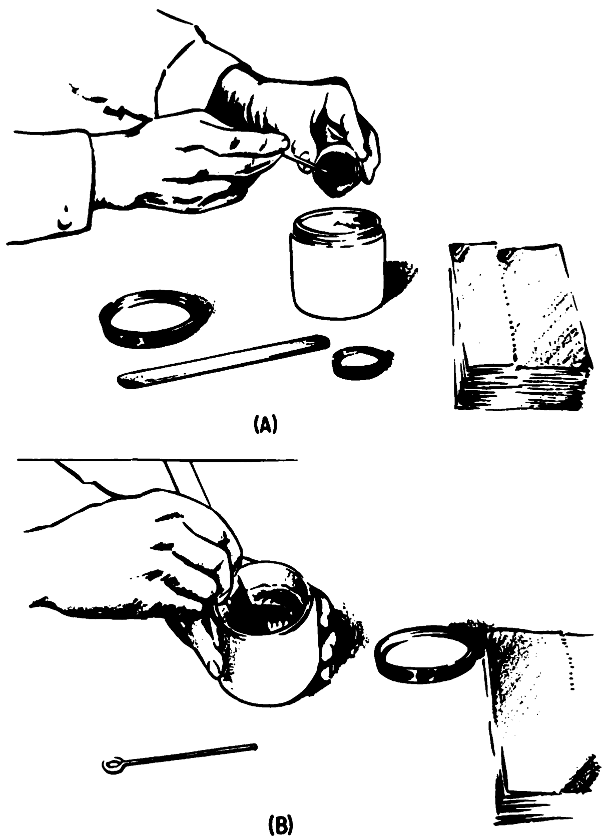


Figure 4-23.—(A) Combining accelerator with base compound; (B) mixing accelerator with base compound.

3. Place the plugs or receptacles on a table, arranging them so that gravity will draw the sealer to the bottom of the plug. Box receptacles or plugs without back shells must be fitted with a mold from masking or cellophane tape or equivalent. This will retain the sealant during the curing process. If the back shell is used, apply a slight amount of oil to the inner surfaces to prevent the compound from adhering to it. (See fig. 4-24 (A) and (B).)

4. The compound is applied by a spatula, putty knife, or paddle. It should be packed around the base of the pins. The part being potted should be completely filled or at least to a point to cover 3/8 inch of insulated wire. The compound is now allowed to cure; temperature will affect the curing time. The normal curing time is approximately 24 hours.

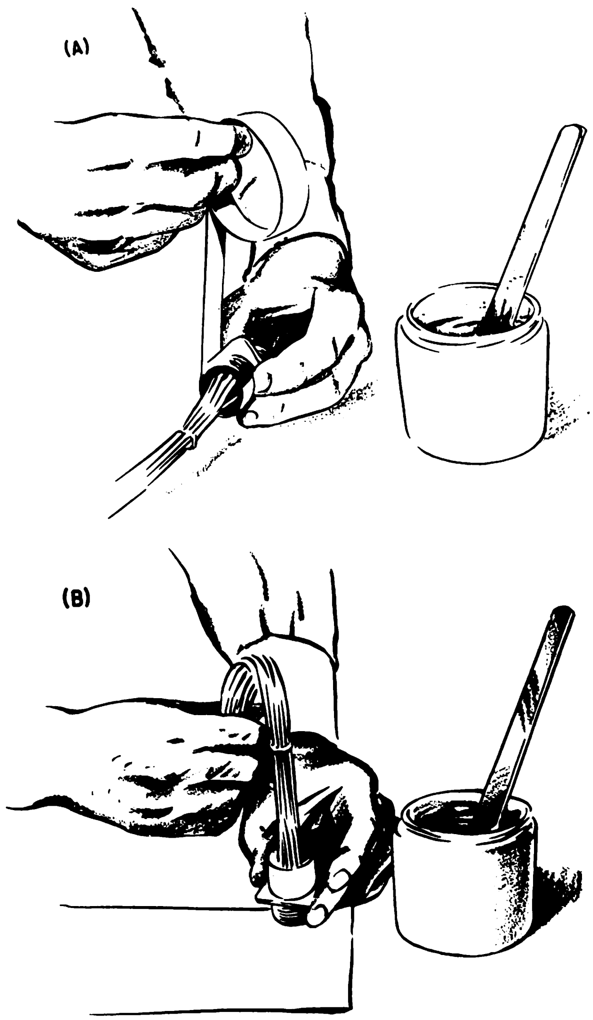


Figure 4-24.—(A) Making mold from masking tape; (B) finished potted plug.

If it is desired that the entire connector assembly (plug and receptacle) be sealed against fluid entering or collecting between the two parts, it is necessary that a rubber O-ring be fitted over the barrel of the plug. This will provide a seal when the two parts are engaged securely. If properly installed, this seal will prevent moist air from entering due to variations in temperature, altitude, or barometric pressure on the ground. Rubber packing O-rings are available

for this purpose through normal supply channels. Due to the aging of these rings in service, it is necessary to examine them each time the connector is disassembled. If deteriorated, they must be replaced.

The purpose of soldering a short length of wire to each spare pin is to provide for two eventualities: to allow for growth requiring additional circuits to be included in the connector, or to reduce the need of repairing a single wire which may have failed within the connectors by making a splice to one of the spare wires. In the event a spare wire is not available in the connector and a single wire must be replaced, the back shell may be removed. This may require considerable force, depending on how well the sealant adheres.

Access to the desired lead and solder cup may be obtained by cutting away the compound with a knife. If a center wire of a large connector is defective and is beyond easy reach from the side, it may be better to remove the sealant from the center with long nose pliers until sufficient area is exposed to allow the defective lead to be repaired. A small soldering gun is required when working in confined places. Complete removal of the compound may be necessary. The plug may be returned to its original condition by applying sealant to the connector in the manner previously described. The new compound will seal or vulcanize satisfactorily any old compound remaining in the connector.

TERMINAL BLOCKS

Terminal blocks are made from an insulating material which supports and insulates a series of terminals from each other as well as from ground. They provide a means of installing terminals within junction boxes and distribution panels.

Two methods of attaching cable terminals to terminal blocks are illustrated in figure 4-25. In (A) of the figure a standard nonlocking nut is used. In this method of installation, the use of a lockwasher (AN 935) is necessary. The preferred method is shown in (B) of the figure. An anchor nut, or self-locking nut, is used and the lockwasher is omitted. The use of anchor nuts is especially desirable in area of high vibration. In both installations, it is required that a flat washer (AN 960) be employed, as shown in the drawing.

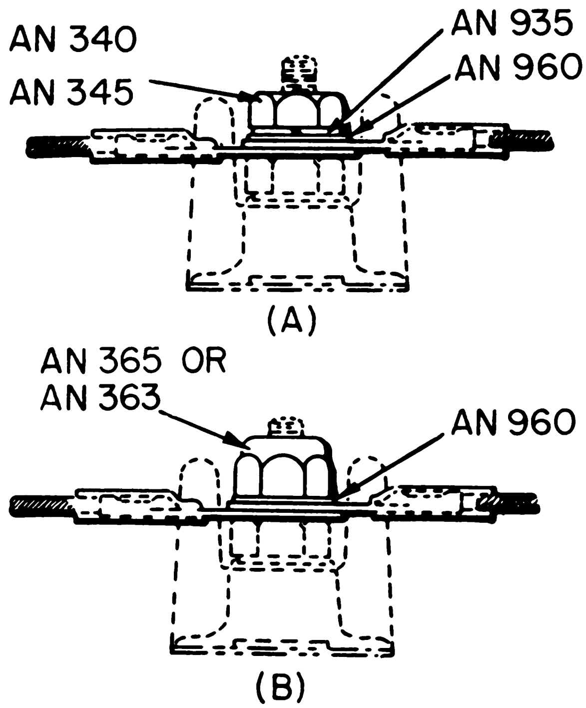


Figure 4-25.—Installation of cable terminals on terminal block.

JUNCTION BOXES

Junction boxes are installed to accommodate electrical terminals or other equipment. Individual junction boxes are named according to their function, location, or equipment with which they are associated. Examples are camera junction box, lower main junction box, and forward right inboard junction box. Junction boxes are provided with a drain hole (except boxes labeled "vaportight") located at the lowest point so that water, oil, condensate, or other liquids will not be trapped.

Figure 4-26 shows a typical junction box for housing and protecting a number of terminal blocks.

SUPPORT CLAMPS

Clamps are used to provide support for conduit and open wiring, and to serve instead of lacing on open wiring. They are usually supplied with a rubber cushion or are of all plastic construction. When used with shielded conduit, the clamps are of the bonded type (fig. 4-27 (A)); that is, provision is made for electrical contact between the

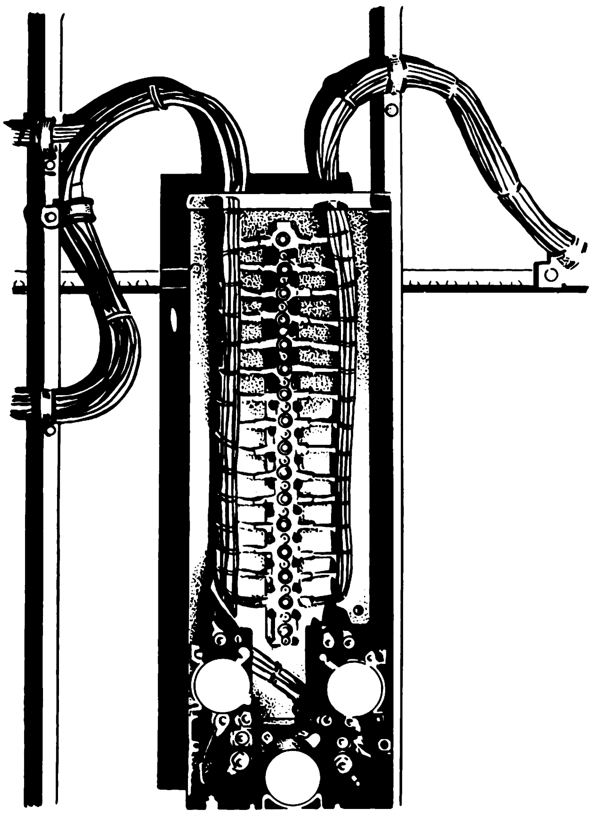


Figure 4-26.—Aircraft junction box.

clamp and conduit. Unbonded clips are used for the support of open wiring. (Bonding is discussed later in this chapter.)

Long runs of cable between panels are supported either by an MS 25281D strap type clamp (fig. 4-27 (B)), or by an AN 742 clamp (fig. 4-27 (C)). The preferred method of supporting cables for all types of runs is with AN 742 or MS 25281D clamps. MS 25281D plastic clamps may be used where the maximum temperature

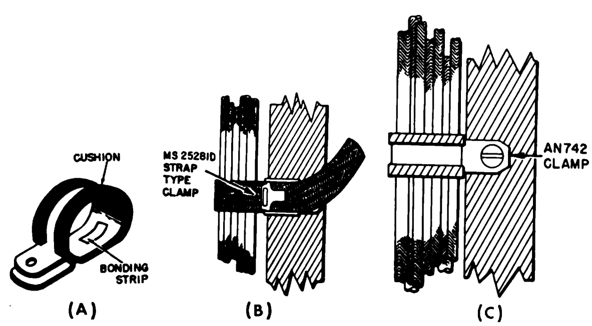


Figure 4-27.—Cable clamps.

does not exceed 250° F. When the strap type clamp is used, precautions must be exercised to insure that they will hold the cables firmly away from lines, surface control cables, pulleys, and all movable parts of the aircraft; these clamps should be used only as an emergency measure.

When cables pass through lightening holes, the installation should conform to the examples shown in figure 4-28. In each case, the cable is held firmly by an AN 742 cable clamp and an AN 743 bracket. The cable should be routed well in the clear of the edges of the lightening hole, to avoid any possibility of chafing of the insulation.

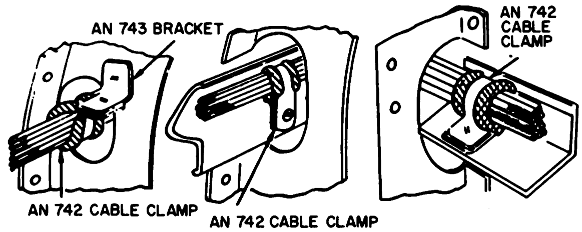


Figure 4-28.—Routing cables through lightening holes.

SHOCK MOUNTS

The protection of electrical and electronic equipment from the effects of vibration is a major problem in aircraft. Almost all amplifiers, instruments, and other fragile parts are usually protected by shock mounting. Shock mounts are sometimes referred to as vibration insulators. The failure of many systems can be traced to faulty shock mounts. The AE should be constantly aware of the importance of shock mounting. A good maintenance practice to follow is to check shock mounts periodically to insure that they are replaced before the equipment has become damaged.

Figure 4-29 shows two types of shock mounts used in naval aircraft. Part (A) of the figure shows mounts that can be replaced individually. Each mount has a rod which extends into the vibration eliminating material. This type of mount may be replaced by drilling out the rivets in the mounting base and riveting the replacement in position. It is important that the replacement be of the same size and type as the mount that is being replaced. The weight of the unit to be protected determines the type mount that will be used. If a mount designed for a heavier unit is used, it will not "give" to protect the unit. If a mount designed for a lighter unit is

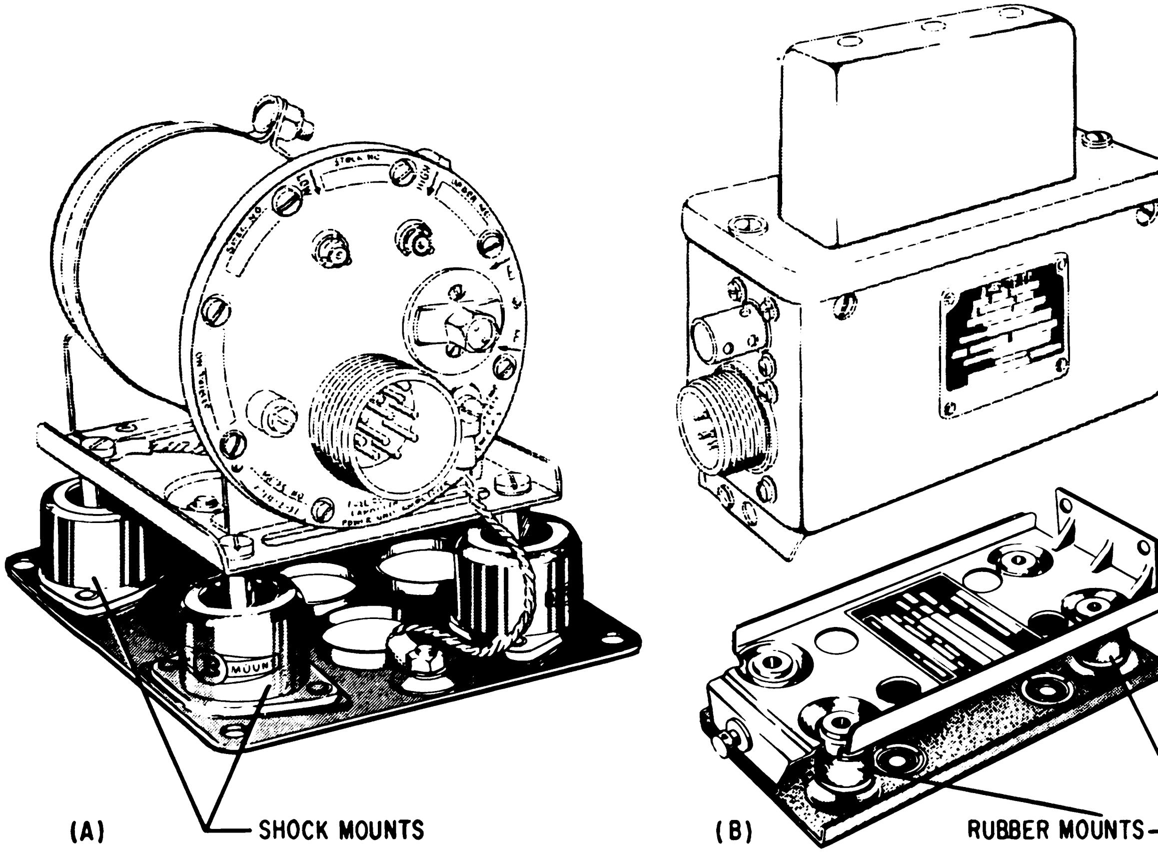


Figure 4-29.—Typical shock mounts.

used, it can easily pull away from the base and cause the unit to be damaged.

The shock mount unit shown in figure 4-29 (B) is designed for a particular unit of equipment. This type of mount must be replaced as a unit. The vibration insulators are made of hollow rubber and locked into place when manufactured. These must be checked for cracks or splits. If one is damaged, the complete unit should be replaced.

CONDUIT AND FITTINGS

In many aircraft the use of conduit is eliminated to a marked degree. This is advantageous in that it saves weight and insures the wide separation of cables; this separation makes the electrical system less vulnerable to gunfire. However, some current aircraft, especially those with limited space for wire routing, utilize conduit.

Conduit is made in two basic types—fl and rigid. Its chief functions are to act as shielding, and as a support and protecti wires.

Conduit fittings are used for attaching flexible or rigid conduit to junction boxe other equipment, and mainly include ferrul coupling nuts. Various forms of both are along with special designs of locknuts, box nectors, and coupling adapters.

Couplings are made in straight or an designs to fit all needs. Ferrules are bushings or flanges applied to the ends conduit to obtain greater strength and to su the coupling nuts. They are either crimp swaged on by the use of crimping or sw tools.

TERMINALS AND SPLICES

Since most aircraft wires are stranded necessary to use terminal lugs to hold the st

together and facilitate fastening the wires to terminal studs. The terminals used in electrical wiring are either of the soldered or crimped type. Terminals used in repair work must be of the size and type specified on the electrical wiring diagram for the particular models. Crimped type splices and terminals are the recommended and preferred type for use on naval aircraft. Soldered type splices and terminals should be used only in emergencies.

The increased use of crimp-on terminals is based to a large degree upon the limitations of soldered terminals. The quality of soldered connections depends mostly upon the technician's skill. Such factors as temperature, flux, cleanliness, oxides, and insulation damage due to heat also contribute to defective connections when they are not precisely controlled.

The crimp-on solderless terminals require relatively little technical skill. Another advantage is that the only tool necessary is the crimping tool, thus the necessity of supplying power to a soldering iron is eliminated. This allows terminals to be applied in an aircraft with a minimum of time and effort. The connections are made more rapidly, are cleaner, and are more uniform. Due to the pressures exerted and the materials used, the crimped connection or splice, properly made, has an electrical resistance that is less than that of an equivalent length of wire.

The basic types of terminals are shown in figure 4-30—(A) shows the straight type, (B) the right angle type, (C) the flag type, and (D) the splice type. There are also variations of these types, such as the use of a slot instead of a terminal hole, three- and four-way splice type connectors, and others.

Since both copper and aluminum wiring is used in current aircraft, both copper and aluminum terminals are necessary. Various size terminal or stud holes will be found for each of the different wire sizes. A further refinement of the solderless terminals is the insulated type; the barrel of the terminal (fig. 4-30) is enclosed in an insulation material. The insulation is compressed along with the terminal barrel when crimping, but is not damaged in the process. This eliminates the necessity of taping or tying an insulating sleeve over the joint.

There are different types of crimping tools used with copper terminals. For wire sizes AWG (American Wire Gage) 10 or smaller, the AN 3428 crimping tool is used on uninsulated terminals. (See fig. 4-31 (A)). When insulated terminals for wire size AWG 10 or smaller are installed, the MS 25037 C crimping tool should be used. (See fig. 4-31 (B)). For the larger wire sizes, crimper dies are used. The small plier type crimper has several sizes of notches for the different size terminals. For large size terminals, individual crimping dies are available for each size terminal. Care should be exercised to select the correct crimping tool for the particular terminal.

The procedure for crimping a copper terminal to a copper wire is as follows:

1. Cut a 1 1/4-inch length of tubular insulation, clear vinyl tubing, and slip it over the

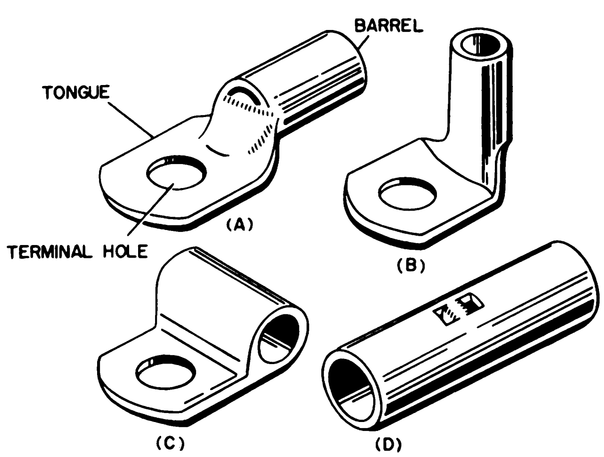


Figure 4-30.—Basic types of solderless terminals.

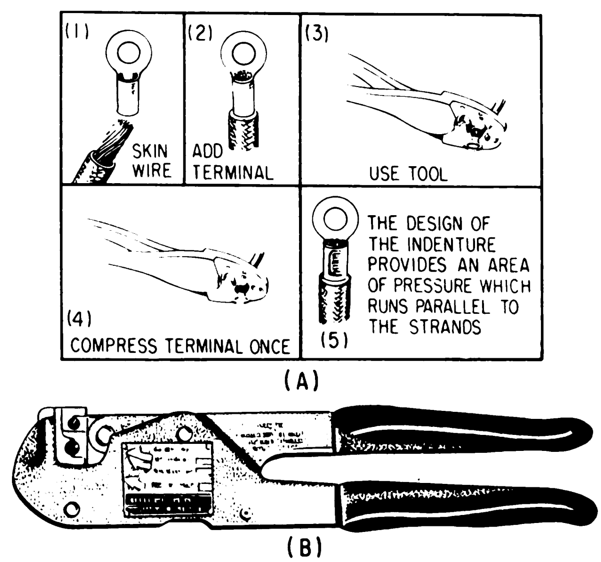


Figure 4-31.—Crimping tools.

end of the cable. This insulation should fit snugly over the cable and must be forced-fit over the terminal.

2. With a cable stripper or other means (fig. 4-32), trim the insulation from the cable end for a length of 1/16 inch plus the length of the terminal barrel. When using a cable stripper, be sure to use the correct size stripping slot for the cable size used; otherwise all the insulation will not be removed or, if the slot is too small, the outside strands of the conductor will be nicked; and consequently weakened. When using a knife for stripping cable, care should be used to prevent strands from being cut or nicked.

3. Slip the terminal barrel over the bared cable end and up against the insulation. Make certain that all cable strands are inside the tubular barrel of the terminal.

4. Crimp the barrel of the terminal with the correct crimping tool or dies of the correct size and type. For uninsulated terminals, sizes 22 through 4/0, center the terminal barrel in the female nest of the crimping tool so that the indentation formed by the male indentor is centered in the barrel. Crimp until the tool reaches its stop or limit. For insulated terminals, sizes 26 through 4/0, position the terminal so that the tongue end of the barrel comes to rest against the locator or stop of the crimping tool or die. Crimp until the tool or die reaches its stop or limit. These procedures are necessary for a satisfactory mechanical and electrical connection.

5. Slip the tubular insulation down over the shoulder or barrel of the terminal so that it extends a little beyond the barrel.

Terminals that are used with aluminum wire are made of aluminum and have been tinned by the manufacturer. Proper crimping is more difficult with these terminals because of such factors as aluminum creep and softness. The softness of aluminum wire also makes it subject to being cut or nicked during stripping. Because aluminum terminals are used only with AWG size 8 and larger wire, the crimping tool is the large pincer type. CAUTION: Never use an aluminum terminal with copper wire or a copper terminal with aluminum because of the battery effect. Also, never attempt to install any aluminum terminals with copper crimping tool, and conversely, never use the aluminum crimping tool for crimping other than aluminum terminals.

The procedure for crimping an aluminum terminal to an aluminum wire is as follows:

1. Carefully remove the conductor insulation; do not cut or nick the aluminum conductors. (NOTE: Do not wire-brush or scrape the aluminum conductor; the compound in the terminal barrel will satisfactorily clean it.)

2. Remove the protective cap or plug from the wire entrance end of the terminal and check the amount of compound in the terminal barrel. It should be 1/4 to 1/2 full.

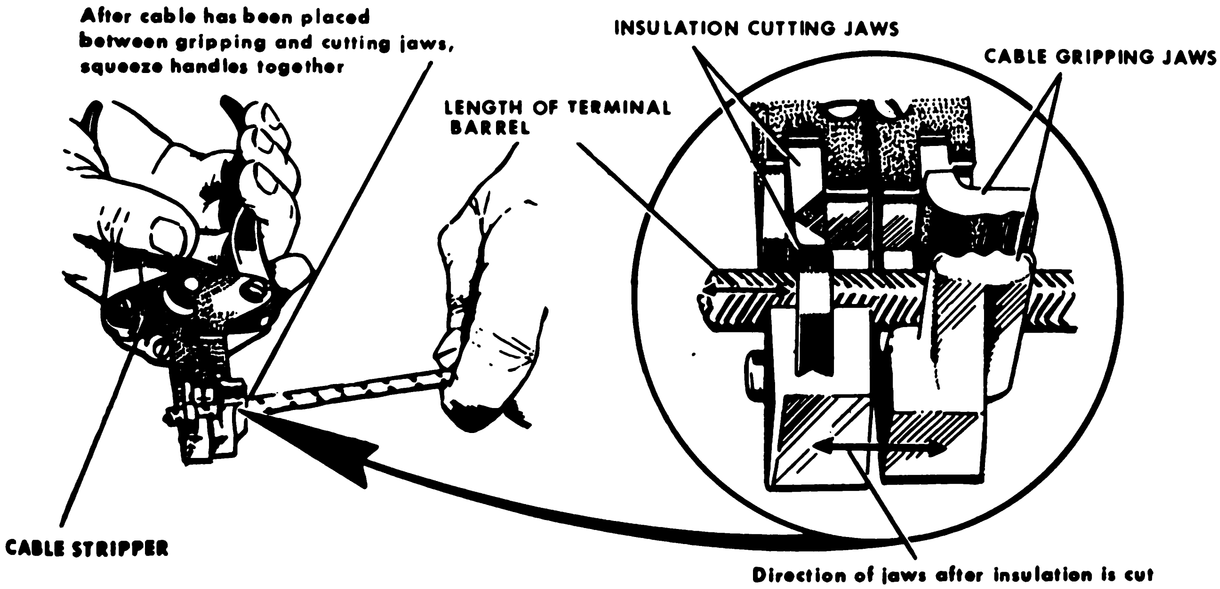


Figure 4-32.—Cable stripper.

3. Insert the stripped conductor the full length of the terminal barrel. While doing this, the thumb must be held over the inspection hole so that the compound is forced in and around the strands.

4. Center the terminal in the crimping tool.

5. Raise the lower nest of the crimping dies so that the terminal is re-formed between the upper and lower nest. The crimp is completed when an audible click is heard or the lower nest returns automatically to its original position.

6. Wipe off the excess compound. Remove the inspection plug and inspect the joint with a probe through the inspection hole. The end of the conductor should come to the edge of the inspection hole. Replace the inspection plug.

Improper crimping procedures will eventually cause terminal failure. Be particularly careful of undercrimping, overcrimping, the use of wrong crimping tools, improper cleaning methods, and cutting or nicking the conductors. A loose contact will allow an oxide film to form between the wire and terminal; this will result in increased resistance and the resistance will cause heat. The heat will accelerate the deterioration and eventually results in a failure. A lockwasher should never be used next to an aluminum terminal since it will gouge out the tinned area and thus increase deterioration. A flat washer should be used, thus preventing the revolving nut from scratching the tinned area or causing creep of the aluminum terminal.

If the correct tools are used and the proper procedures followed, the connections are more effective electrically, as well as mechanically, than soldered connections. A visual inspection is very important; it will reveal oxidation, deterioration, overheating, and broken conductors. In some cases it may be necessary to check these connections with an ohmmeter; the proper resistance, for all practical purposes, should be zero. Any defective terminal should be removed and a new terminal crimped on.

A cable splice, other than one made with the crimp-on splice or connector, is employed as an emergency measure only. Solder may or may not be used, as the condition warrants, but in any case the splice should give a good electrical and mechanical joint without solder. The splice should be taped to give insulation equivalent to the rest of the cable. A permanent repair must be made as soon as possible.

Consult section XII fo Engineering Handbook Series for Aircraft Repair, Aircraft Structural Hardware (NW 01-1A-8) and/or Installation Practices for Aircraft Electrical and Electronic Wiring, NavAer 01-1A-505, for detailed information dealing with attaching cable terminals, forming terminals for emergency use, and repairing damaged or broken cables.

METAL FASTENERS

Metal fasteners are used to secure cowling, fairing, inspection plates, and access panels and doors. Even though they are maintained by other rates, the AE may be called upon to assist in their repair and replacement. An understanding of their construction and use will also enable him to use them properly.

There are various types of metal fasteners, but for this discussion the turnlock fasteners are used as typical examples. Figure 4-33 shows a light-duty type fastener. It is used on panels, junction box doors, and inspection plates.

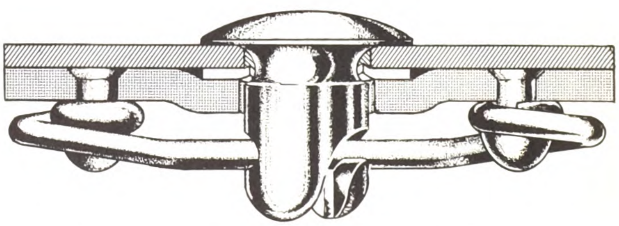


Figure 4-33.—Turnlock fastener, light-duty type.

The stud assemblies of the various fasteners are either slotted for screwdriver operation or have a winged head; these are used for fastening and unfastening. Figure 4-34 shows a type of fastener in which a spring in the stud assembly provides a positive lock of the fastener. Stud assemblies are assembled at the factory and should not be disassembled. To install the assembly, compress the spring and insert the stud assembly into the grommet. Once installed into the grommet, the stud assembly cannot be removed unless the spring is again compressed.

There are various types of fastener receptacles. Typical receptacles are shown in figure 4-34 and 4-35. The receptacle shown in figure 4-35 is designed in two styles—rigid and floating. The floating type is the more common since it enables the receptacle to move slightly, and

therefore alinement is easier. The receptacles are manufactured from high-carbon, heat-treated steel for long dependable life. They are riveted to the portion of the aircraft to which the panel, door, or inspection plate is to be anchored. The correct procedure for the installation of fasteners is given in NavWeps 01-1A-8, section XI. A good rule to follow when securing a panel, inspection plate, or door is to never force the fastener. If it seems hard to catch or lock, the receptacle may be damaged; forcing may only damage it more. Always compress the spring or stud fully and use an even force. If the stud does not lock, release and turn the stud slightly to realine. Always use the proper tool for locking the fasteners.

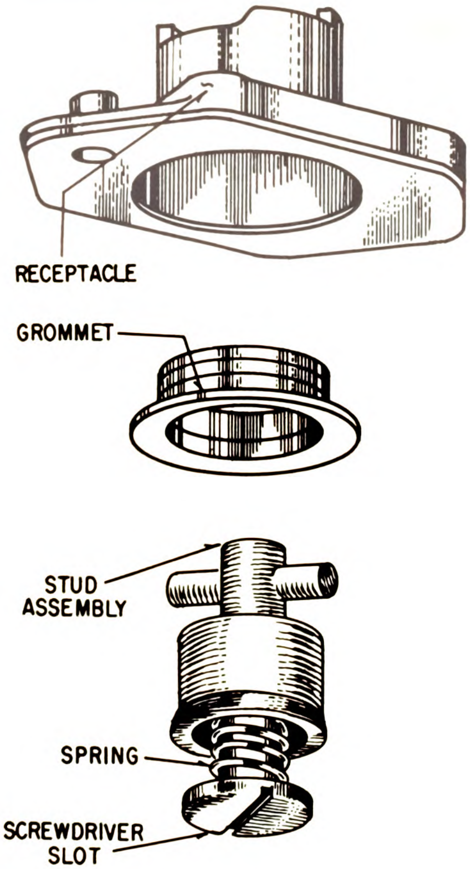


Figure 4-34.—Turnlock fastener.

WIRING INSTALLATION

CIRCUIT FAULTS ON AIRCRAFT

Circuit fault may well be described as any action that causes the circuit to open, ground, or short. The effect of these faults is to decrease or cut off the current, or to increase it beyond a safe value.

Open circuits may result from dirty, broken or loose connections. Connections are made through binding posts, plugs, switches, receptacles, and soldered or friction lugs. Good connections are clean and tight. If a connection is perfectly clean, contacts over a large area, and is tight, negligible resistance is added to the circuit. But if the connection is dirty, of small contact area, or is loose, a considerable amount of resistance is introduced in the circuit.

After electrical apparatus has been in operation for some time, vibrations may have produced loose connections. It is easy to spot a loose connection since it sparks, becomes extremely hot, and the current strength drops below its rated value. Loose connections, because of their arcing, are fire hazards and may burn insulation.

The true open circuit occurs when a wire breaks or when a connection comes completely apart. The circuit is broken and no current flows. Opens may also result from poor running of cable; cables should have no kinks or sharp bends.

Short circuits are "shortcuts" between the terminals of a source of electrical power. Imagine that the insulation is destroyed within the cable run of a portable light. The two conductors within this cable contact each other. Figure 4-36 shows this schematically. The current in this circuit now travels from the source to the short (point of contact) and back to the source. The short has provided an easier path of low resistance.

The current is extremely high because the short offers practically no resistance to the current. This current may be high enough to heat the wires to a red heat, melt the insulation, burn out the generators, and sometimes cause a fire.

Most shorts are accidental. They occur as a result of vibration, when salt water is allowed into a section of cable, when heat melts away insulation, and when carelessness brings two conductors together. Commonsense and reasonable care will reduce shorts to a minimum.

Grounded circuits are of two types—intentional and accidental. Intentional grounds are used on aircraft in which one terminal of the battery or generator is connected to the fuselage and constitutes a ground connection. The

other terminal of the source is connected to the loads, which are also grounded. The current path is from source to load via a wire and return to source via the metal framework (ground). Actually the metal framework is being used as one of the two conductors. An accidental ground from the "hot" side (ungrounded terminal) to the framework would be a short circuit through the aircraft. Figure 4-37 shows the difference between intentional grounds and accidental grounds.

Opens, shorts, and accidental grounds either interrupt a circuit completely or, at least, impair its efficiency. In general, there are only a few causes of circuit faults; these are given as follows:

Cause	Defect
Dirt and grease. . .	Poor or open connection.
Loose lugs and bolt connections.	Poor or open connection.
Heat	Shorts, opens, or grounds.
Deteriorated insulation.	Shorts or grounds.
Friction, chafing . . kinks, and nicks.	Opens, shorts, or grounds.
Acids and paints . .	Ruined insulation, shorts, opens, or grounds.
Overloads	Heat or opens.
Small area connections.	Heat, low current, or opens.

CIRCUIT PROTECTORS

The electrical system of an aircraft is protected from damage and failure by fuses, circuit breakers, current limiters, and sectionalization.

Fuses

The simplest overcurrent device is the fuse. A fuse is a short length of wire or metal ribbon within a suitable enclosed container. This ribbon (or link) is usually made of an alloy that has a low melting point and of a size which will carry a given amperage indefintely. A larger current causes the metal to heat and melt, opening the circuit to be protected. Most fuses are made of an alloy of tin and bismuth; but copper, aluminum, German silver, or iron alloys have been used. A fuse is always placed in series with a circuit so that it opens the circuit automatically.

The standard type fuse used in naval aircraft is the cartridge fuse. The more common types of aircraft fuses and fuse holders are shown in

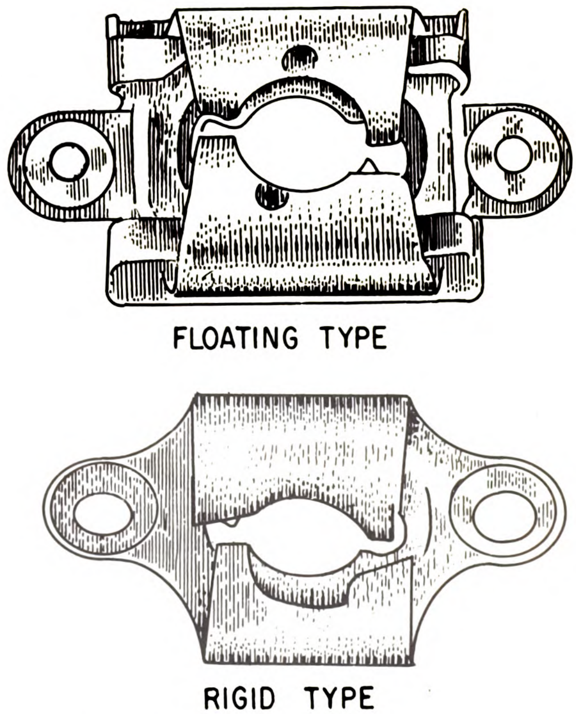


Figure 4-35.—Fastener receptacles.

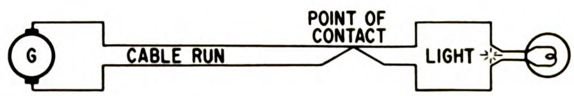


Figure 4-36.—Short circuit.

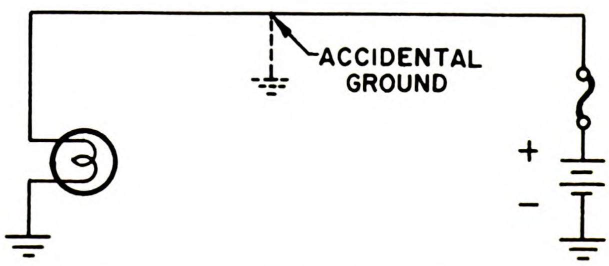


Figure 4-37.—Intentional and accidental grounds.

figure 4-38. The current capacity of each fuse is marked on the side of one of the ferrules (caps). These cartridge fuses are made in various physical sizes. The size is indicated by an AG number (such as 3AG, 4AG, etc.) which indicates a glass body and an AB number (such as 3AB, 4AB, etc.) for a bakelite body. Fuses may be further classified as instantaneous or time delay types. The instantaneous fuse will carry its rated current indefinitely but must quickly open the circuit when its rated capacity is exceeded by about 25 percent.

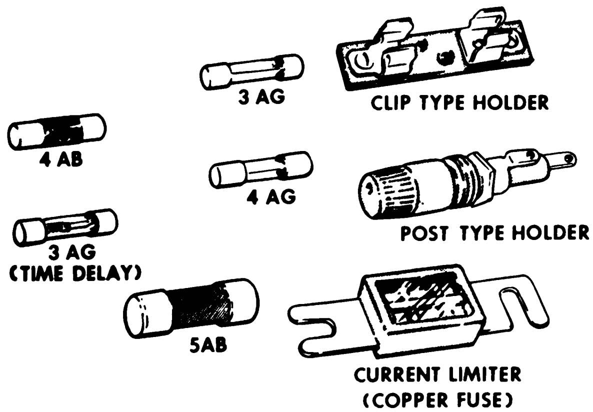


Figure 4-38.—Aircraft fuses and fuse holders.

Time delay fuses are designed to have a time delay for overloads. This feature is necessary to keep short-time surges, such as high starting current for motors, from melting (blowing) the fuse. This time delay permits momentary high current without injuring the fuse, while continuous excessive current results in a rupture of the fuse. The time delay can be accomplished by making the fuse link of heavy construction except in one or two short portions of its length. This allows the heat to be drawn away from the small high resistance portions, thereby delaying the melting time.

Fuses used in aviation are not the reusable or repairable type. They must be replaced with a new fuse after the defect in the equipment has been repaired.

Another consideration in the use of a fuse is the voltage rating. This rating refers to the maximum voltage possible in the circuit in which the fuse is to be used. It is the voltage that the fuse construction can safely handle without arcing. If a fuse opens, the entire applied voltage of the circuit will appear across it. Therefore, the voltage rating of the fuse should be higher than the maximum circuit voltage.

Current limiters are devices somewhat similar to fuses and are used in aircraft circuits that carry high currents. (See fig. 4-38.) This circuit protector consists of a copper link of carefully predetermined sections. These sections fuse and protect aircraft power circuits when a circuit becomes shorted. For example, these limiters protect the remaining circuits of a power bus by removing the shorted circuit, thereby enabling the other circuits to function normally. It is important to replace a current limiter with the proper type since a time delay type would not provide the proper protection in a circuit that requires an instantaneous type.

Sectionalization is the arrangement of electric components and devices to provide alternate paths of power to the components. Thus, if an electric circuit to an actuator for example, is broken by gunfire, the actuator receives power from an alternate path. Sectionalization increases the number of circuit paths and junctions. An example of sectionalization is the decentralized type of power bus system used in the P-2H aircraft.

From the primary d-c bus in this aircraft, feeder bus cables lead to the various buses, such as the waist bus, forward load center bus, nose bus, etc. The feeder bus cables are protected at each end by current limiters which serve to isolate faults in individual cables. As a further assurance of continuous power, three (or more) feeder bus cables are used in each case, any two of which are capable of carrying the total load alone in the event that one of the others becomes isolated from the circuit due to shorts, breaks, or grounds.

When a high current fault occurs in the main power distribution system, all current limiters between the fault and the primary bus are subjected to an overload which may have affected their current-carrying capacity. Therefore, when such a fault is discovered, all limiters in the power circuit back to the primary bus must be replaced. When in doubt about the magnitude of fault, replacement should be accomplished, since damage to the limiters may not always be visible.

Circuit Breakers

In most current aircraft, a comparatively small device protects most of the wires and cables making up the electrical system. This

device is the circuit breaker. It is designed to open the circuit under short-circuited or overloaded conditions without injury to itself. Thus, it performs the same function as the fuse, but has the advantage that it is capable of being reset and used again. In the same manner as the fuse, the circuit breaker is rated in amperes and voltage.

Circuit breakers used in naval aviation are commonly categorized according to the way that circuit breaking action is initiated—thermal, magnetic, or thermomagnetic. The coverage here is directed primarily to thermal circuit breakers, as these are more widely used. Thermal circuit breakers are further divided into subcategories or types according to the means by which they are reset—the pushbutton reset type (sometimes called a circuit protector).

The pushbutton reset type consists of a bimetallic, thermally (heat) actuated, spring-loaded device which closes the two electrically contacts when set. This is shown in figure 4-39. An excessive current through the device causes an uneven expansion of the bimetallic mechanism (thermal release) which releases a trigger escapement. This release permits the spring loading to rapidly separate the movable and stationary contact members.

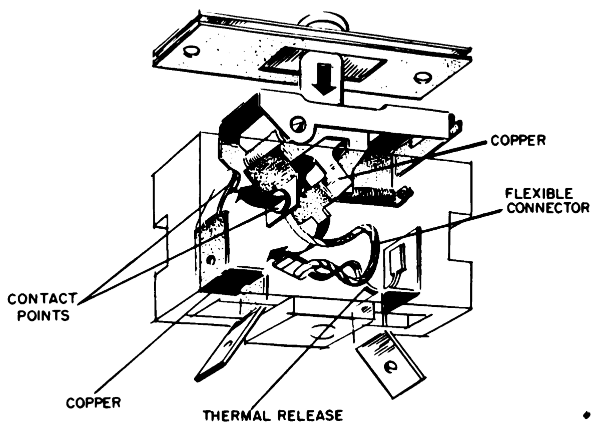


Figure 4-39.—Thermal circuit breaker.

A visual indication of the automatic opening is provided by causing the pushbutton to move to an easily noticed "tripped" position. In this position the button is fully extended and the white ring, plus the inner red section of the button, is showing. The latest type of pushbutton breakers have a pullout feature which permits manual opening of the circuit, but this type should not be used as a switch.

In place of the pushbutton actuator, a toggle lever is used on another type of circuit breaker. It operates like the previously discussed breaker with the exception that the tripped condition is indicated by the toggle lever being in the OFF position. This type of circuit breaker has the apparent advantage of use as a switch.

Manual resetting of the circuit breaker may be accomplished by means of the actuator (either pushbutton or toggle lever) whenever the bimetallic thermal element cools sufficiently for the trigger to engage its latching mechanism. In connection with resetting, there are two other classifications for circuit breakers; namely, trip-free and non-trip-free. The non-trip-free circuit breakers can be maintained closed by the operator's action while a tripping condition exists. This should be done only in an emergency and since this action is apt to change the calibration of the breaker it should be replaced. This type breaker is no longer being installed in new aircraft; however, it may still be found on older aircraft.

In the trip-free classes the contacts cannot be maintained closed by manually holding the actuator in the closed, or reset, position as long as an overload condition persists, which would otherwise cause normal tripping.

Another type of thermal circuit breaker is shown in figure 4-40. This breaker consists of a conductive bimetallic snap-acting disk which bridges two electrical contacts. When this disk is heated by the excess current through it, it snaps in reverse position, opening the contacts and thereby breaking the circuit. In the circuit breakers having low ratings, a resistance wire is inserted in the circuit. The heat developed in this wire provides the heat necessary to snap the disk. These circuits are reset by pressing the button which restores the disk to its original position. Once this type of circuit breaker is closed it cannot be reopened manually. This type is also nonindicating; that is, the position of the breaker (open or closed) cannot be determined by visual inspection.

The automatic reset type circuit breaker is similar to the bimatallic disk type just described except that it has no reset pushbutton; it resets itself automatically. After a short time, when the disk has cooled sufficiently, it will bend back and close the circuit, resetting itself. If a constant overload exists, the breaker will intermittently break the circuit.

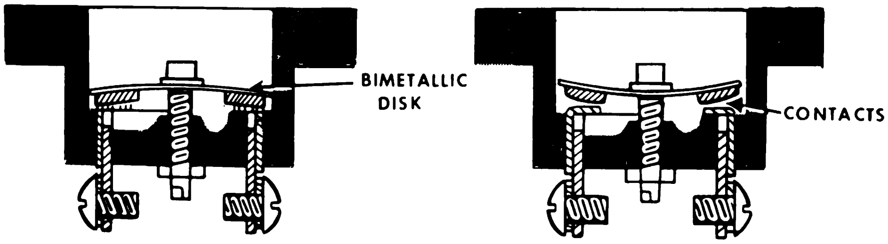


Figure 4-40.—Thermal circuit breaker.

Another type of circuit breaker is the switch toggle variety based on magnetic instead of thermal operation. This type can be made to open almost instantly when more than the rated current flows in the circuit. To accomplish this, an electromagnet is placed in series with the contacts and the contacts are mounted on an armature. When an excess current flows through the device, the armature is pulled toward the electromagnet, opening the contacts and thereby the circuit. The armature is then latched in the off or tripped position. To reset the circuit breaker, the armature is unlatched and returned to the normal position.

Maintenance

The maintenance of fuses is a very simple operation. When the fuse has a glass body, a visual inspection will disclose an open fuse. If there is any doubt as to the condition, a continuity test will readily indicate an open or closed fuse. If the fuse is defective, it must be replaced.

Occasionally the fuse holders will become defective. Here once again, the maintenance required is a visual inspection followed by a continuity test. If the holder is found to be defective, it should be replaced.

Circuit breaker maintenance presents a little more difficulty due to the possibility of a change in current capacity. This change may result from usage over a period of time and is difficult to detect. If the current-carrying capacity increases, the circuit protection value is reduced. If the current-carrying capacity decreases, the circuit breaker will open with less than rated current. Normally, under this condition, the circuit breaker is the last component suspected because its opening usually indicates a circuit failure.

The usual maintenance of breakers involves a visual inspection of the terminals and continuity checks. If a breaker malfunctions or appears to be operating improperly, it should be removed and replaced by a new device of the same type and rating.

BONDING AND BONDING DEVICES

A bond is any fixed union existing between two metallic objects that results in electrical conductivity between them. Such a union results from either physical contact between conductive surfaces of the objects or from the addition of a firm electrical connection between them. Aircraft electrical bonding is the process of obtaining the necessary electrical conductivity between the component metallic parts of the aircraft. An isolated conducting part or object is one that is physically separated by intervening insulation from the aircraft structure and from other conductors which are bonded to the structure.

A bonding connector provides the necessary electrical conductivity between metallic parts in an aircraft not in sufficient electrical contact. Examples of bonding connectors are bonding jumpers and bonding clamps.

PURPOSE

Clouds may become highly charged, as is evidenced by lightning. An aircraft can also become highly charged while in flight. If the aircraft is improperly bonded, all metal parts will not have the same amount of charge. A difference of potential will then exist between various metal surfaces. The neutralization of the charges flowing in paths of variable resistance, due to such causes as intermittent contact caused from vibration or the movement of the control surface, will produce electrical disturbances (noise) in the radio receiver. If the resistance between isolated metal surfaces is

great enough, charges can accumulate until the potential difference becomes high enough to cause a spark. In addition to creating radio interference, this also constitutes a fire hazard. In the case of lightning striking the aircraft, a good conducting path is necessary for the heavy current in order to minimize severe arcs and sparks which would damage the aircraft and possibly its occupants.

The aircraft structure is also the ground for the radio. For the radio to function properly, a proper balance must be maintained between the aircraft structure and antenna. This means the surface area of the ground must be constant. Control surfaces, for example, may at times become partially insulated from the remaining structure due to a film of lubricant on the hinges. This would affect radio operation if the condition were not taken care of by bonding.

Bonding also provides the necessary low-resistance return path for single-wire electrical systems. This low-resistance return path also aids the effectiveness of the shielding, and provides a means of bringing the entire aircraft to the earth potential when it is grounded.

The reasons for bonding may be summed up as follows:

1. To minimize radio and radar interferences by equalizing static charges that accumulate.
2. To eliminate a fire hazard by preventing static charges from accumulating between two isolated members and creating a spark.
3. To minimize lightning damage to the aircraft and its occupants.
4. To provide the proper "ground" for proper functioning of the aircraft radio.
5. To provide a low-resistance return path for single-wire electrical systems.
6. To aid in the effectiveness of the shielding.
7. To provide a means of bringing the entire aircraft to the earth's potential and keeping it that way while it is grounded to the earth.

PARTS REQUIRING BONDING

The trend in current naval aircraft is to keep the number of bonding jumpers to a minimum. As a consequence, the jumpers used are very important and must be replaced whenever necessary to keep them in good condition. A partial listing of the parts of an aircraft that must be bonded are as follows:

1. Ignition harness.
2. Control surfaces. Each control surface should have at least two bonding jumpers. This does not apply to trim tabs.
3. Engine mounts. At least four bonding jumpers capable of continuously carrying a current of 40 amperes should be connected across each engine mount support to provide a current path between the engine mount and aircraft structure.
4. Engine cowling. At least four symmetrically placed bonding jumpers should be used to bond the engine ring cowling to the engine across the rubber mounts at the front end of the cowling.
5. Equipment mounts. Bonding jumpers should be placed across shock mounts used to support electrical and radio equipment or the instrument panel.

METHODS AND MATERIALS

Bonding connections should be installed so that vibration, expansion or contraction, or relative movement incident to normal service use will not break the bonding connections nor loosen them to such an extent that the resistance will vary during the movement.

Since a primary objective for bonding is to provide an electrical path of low d-c resistance and low RF impedance, it is important that the jumper be a good conductor of ample size for the current-carrying capacity, have low resistance, and be as short as possible. Parts should be bonded directly to the basic aircraft structure rather than through other bonded parts insofar as practical. Bonding jumpers should be installed in a manner so as not to interfere in any way with the operation of movable components of the aircraft. (See fig. 4-41.)

Contact of dissimilar metals in the presence of an electrolyte, such as salt water, produces an electric action (battery action) which causes a pitting in one of the metals. The intensity of this electric action varies with the kinds of metals. Bonding frequently necessitates the direct contact of dissimilar metals. In such cases the metals used are of the kind that will produce minimum corrosion. The connections are also made so that if corrosion does occur, it will be in replaceable elements, such as jumpers, washers, or separators, rather than in the bonded or bonding members.

Self-tapping screws should not be used for bonding purposes nor should jumpers be compression-fastened through plywood or other

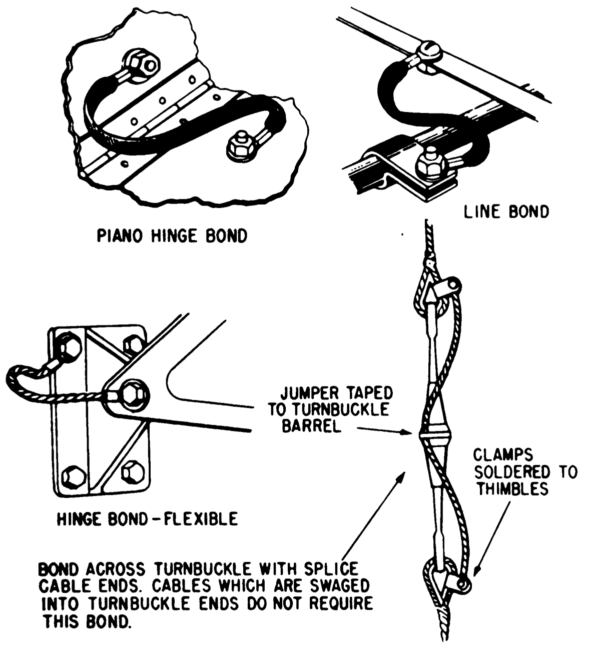


Figure 4-41.—Bonding methods.

nonmetallic material. When performing a bonding operation, the contact surfaces should be cleaned of insulating finishes or surface films before assembling, and then the completed assembly refinished with a suitable protective finish.

Consult Installation Practices for Aircraft Electric and Electronic Wiring, NavAer 01-1A-505, for detailed information dealing with bonding.

SAFETY WIRING

Parts such as drilled-head bolts, fillister-head screws, clips, thumbscrews, plugs, and similar items, are safetied with wire. A zinc-coated, soft-steel wire is usually used for this purpose. Annealed corrosion-resisting wire is also used for specific applications, such as in equipment where nonmagnetic qualities and heat resisting properties are desired.

The double-twist method is the most common method of safety wiring, and should essentially be as shown in figure 4-42. The twisting may be accomplished by hand with the exception of the final few twists which should be done with pliers in order to apply tension and secure the ends of the wire properly. (A handtool to aid in twisting safety wire is the wire twisting pliers.) The safety wire should always be installed and twisted so that the loop around the head stays down and does not tend to come up over the bolthead, causing a slack loop. Extreme care must be used when twisting the wires together to insure that they are tight but not overstressed to the point where breakage will occur under slight load or vibration.

The single-twist method of safety wiring may be used on small screws in a closely spaced area provided the screws form a closed geometrical pattern. Figure 4-42 illustrates a typical application where the single-wire method may be used.

Finished ends of safety wire should be bent back or under to prevent injury to personnel.

Under conditions of severe vibration, the coupling nut of a connector may vibrate loose; and with sufficient vibration, the connector will come apart. When this occurs, the circuit carried by the cable will open. The proper protective measure to prevent this occurrence is by safety wiring as shown in figure 4-43. The safety wire should be as short as practicable and must be installed in such a manner that the pull on the wire is in the direction which tightens the nut on the plug.

In aviation electrical equipment there will be other parts and devices which require safety wiring to prevent loosening, parting, or changing of position. The procedure given for the safety

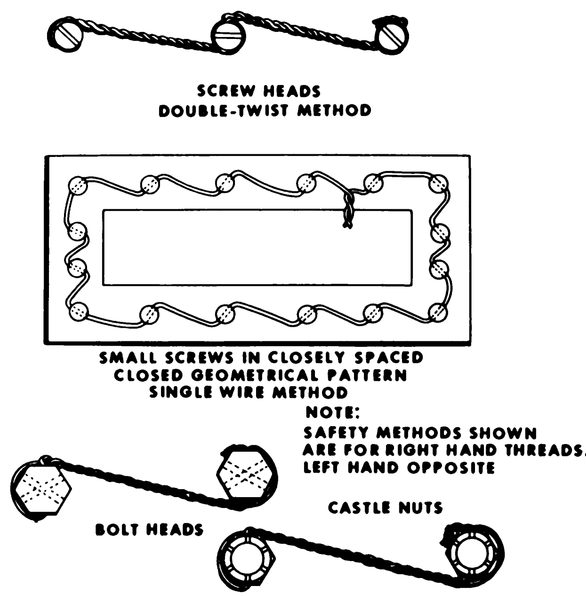


Figure 4-42.—Safety wiring.

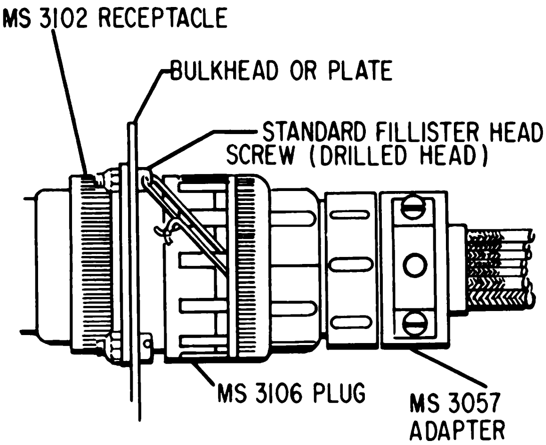


Figure 4-43.—Safety wiring attachment for plug connectors.

wiring of bolts needs only slight modification to fit the particular situation. Whenever a safety wire is broken for maintenance or other cause, it must be replaced using the proper procedure. Any time a required safety wire is not replaced, an in-flight failure may result.

When drilled-head bolts, screws, or other parts are grouped together, they are more conveniently safety wired to each other or in series rather than individually. The number of bolts, screws, nuts, etc., that may be safety wired together is dependent upon the application. For instance, when safety wiring widely spaced bolts by the double-twist method, a group of three should be the maximum number in a series. When safety wiring closely spaced bolts, the number that can be safety wired by a 24-inch length of wire should be the maximum number in a series. The wire is arranged in such manner that if either a bolt, screw, or a threaded item begins to loosen, it will have force applied in the tightening direction. Parts being safety wired should be torqued to recommended values and holes alined before attempting to proceed with the safetying operation. Never overtorque or loosen a torqued nut to aline safety wire holes.

CHAPTER 5

LIGHTING

Primarily, the lighting system in an aircraft serves two purposes—to provide specialized light sources outside the aircraft and to illuminate the interior. Lights on the exterior provide illumination at night for navigation and such other operations as signaling, landing, anticollision, and formation flying. The interior lighting provides illumination for instruments, equipment, cockpits, cabins, and other sections occupied by the crew. In addition, certain special lights called indicator lights are used to indicate the operational status of equipment, such as the position of the landing gear or bomb-bay doors.

Various types and sizes of light assemblies are used on present-day naval aircraft. The selection of a particular assembly is governed by the nature of the lighting that is needed. Generally speaking, a light assembly consists of a housing (fixture), a lamp, and a lens. Various types of lighting assemblies are explained throughout this chapter.

AIRCRAFT LAMPS

Aircraft lamps are devices that are used as sources of artificial light. Two types of lamps are used in naval aircraft—the incandescent and the gas discharge. In the incandescent type the light is obtained from a heated filament and in the gas-discharge type a high-intensity light is produced by an ionized gas.

INCANDESCENT LAMPS

Most of the lamps used in naval aircraft are of the 28-volt incandescent type. In these lamps the filaments frequently burn out prematurely due to vibration. When a lamp is replaced, the replacement must be the same as the lamp that is replaced. Spare lamps that are carried in the aircraft should be shock-mounted; otherwise they are apt to fail earlier than the ones in use since cold filaments are normally more subject to fatigue failure than hot ones.

The parts of a lamp are the bulb, filament, and base. Incandescent lamps vary chiefly in electrical rating, base type, bulb shape, and bulb finish.

The electrical rating is usually expressed as combinations of the following items: volts, watts, amperes, and candlepower. (Candlepower is the luminous intensity expressed in candles and used to specify the strength of a light source.) The lamp rating is marked on either the base or the bulb of the lamp. In the case of small lamps, the electrical rating is usually replaced by an identifying number.

The base types vary as to size, number of electrical contacts, and the method of securing in a socket. The most common bases are the single or double contact bayonet (push in and turn) type. These are desirable for aircraft use since they lock in the socket and do not become loose because of vibration. The single contact is used in single-wire systems. In this system one side of the lamp filament is soldered to the base and the other to the contact. The double contact is used where the single-wire system is not practicable. In this system the filament is connected to the contacts and does not make an electrical connection to the base unless dual filaments are employed, in which case a common contact is made to the base. The single and double contact type lamps cannot be used interchangeably.

Some bases are of the screw type, but they find limited use because they loosen easily. Figure 5-1 shows some of the popular types and sizes of lamp bases used in aircraft.

The sizes of lamp bases are classified by the following terms: miniature, candelabra, intermediate, medium, and mogul. The smaller sizes (miniature and candelabra) are used extensively in aircraft lighting while the larger

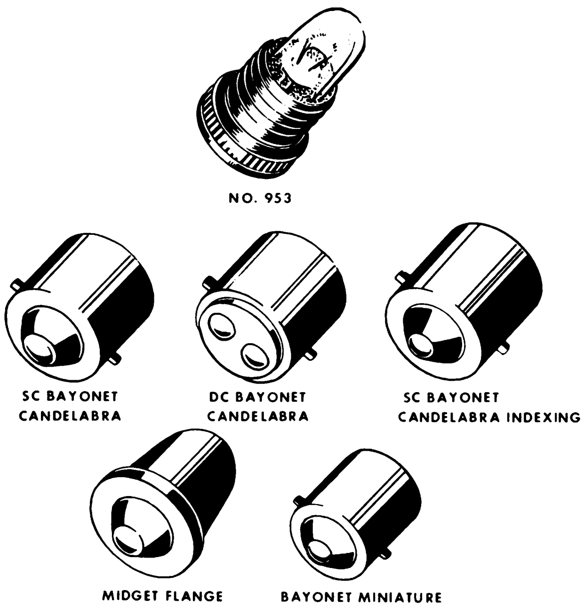


Figure 5-1.—Lamp bases.

sizes (medium and mogul) find use in shop and hangar lighting.

Some lamps, for example the silver bowled type used for directional lighting, are provided with an indexing type base having offset index pins. (See fig. 5-1.) The purpose of this index type base is to assure that the lamp is seated in the socket so that the light shines in the proper direction.

Bulb shapes are designated by the combination of a letter and numeral. The letter designation indicates the shape of the bulb in accordance with a code, and the number is a measure of the approximate maximum diameter of the bulb in eighths of an inch. The shapes of the more common glass envelopes are as follows:

G or globular
T or tubular
S or straight side
PAR or parabolic

For example, a bulb designated as T-6 has a tubular shape and a diameter of three-fourths inch. A variety of sizes and shapes of glass envelopes can be found in the ASO Navy Stock List. Figure 5-2 shows some common bulb shapes.

The majority of aviation lamps are either clear glass or inside frosted. For particular applications, however, bulbs may be partially frosted to cut down emission of light in a particular direction, or they may be partially silvered

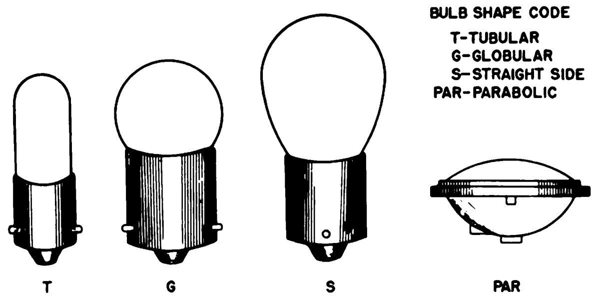


Figure 5-2.—Common bulb shapes.

to prevent emission in specified directions and to concentrate the light in other directions. Some applications call for colored bulbs; for example, in instrument illumination and safety lights. Colored lighting is usually provided by using clear lamps that are covered with colored lenses.

There are many special purpose lamps used in naval aircraft. Three of the most common are as follows:

1. The parabolic, sealed beam landing light (this type lamp is also used in signal lights).
2. The midget flange type lights which are used in instrument panels and control boxes.
3. Lamps having two filaments in parallel to provide fast signaling (smaller filaments heat and cool faster) are used in fuselage and signal lights.

GAS-DISCHARGE LIGHTING SYSTEM

Gas-discharge exterior lighting systems have been installed on some late model jet aircraft to provide high-intensity exterior lighting. This lighting is provided by tubular, gas-discharge lamps which operate in conjunction with ballast and filament transformers. Figure 5-3 shows a typical wingtip, gas-discharge lighting installation.

A ballast transformer is utilized in the system circuit to supply current to the high-intensity lamp. There is one ballast transformer for each lamp. The primary of the ballast transformer is connected to the 115-volt, 400-cycle aircraft power supply. Under normal operation, its secondary produces a varying output voltage of 850 volts, ±50 volts, with an output current of approximately 250 milliamperes. (CAUTION: Extreme care should be taken when checking this system since the high voltages are dangerous.)

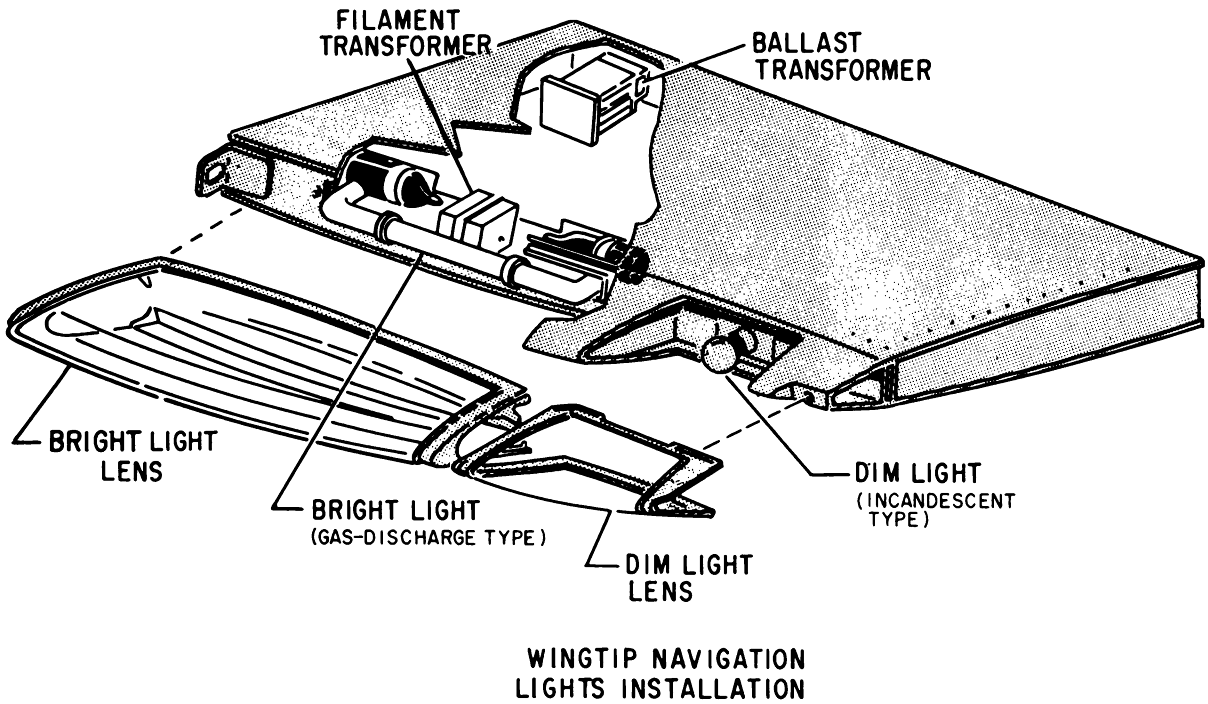


Figure 5-3.—Gas-discharge lighting system.

There is also one filament transformer for each lamp. This transformer reduces the aircraft's 115-volt, 400-cycle supply to a voltage suitable for heating the lamp's starting filaments. Each filament transformer consists of one primary winding and two secondary windings. With the primary winding connected to the 115-volt power source, each secondary produces a 6-volt output. Each secondary is connected to an individual filament at one end of the gas-discharge tube. The heated filaments ionize the gas in the tube, allowing a high-voltage electrical discharge to occur between the electrodes. The electrical discharge through the gas produces light.

There are no previsions for dimming the gas-discharge lighting system. When a dimmer light is desired, the system is deenergized and an incandescent type light is then turned on (fig. 5-3).

As newer high-speed aircraft are developed, prevention of lamp failure becomes a greater problem. This problem is more acute in jet aircraft because of higher frequency vibration which shortens the life of incandescent lamp filaments. For this reason, gas-discharge lamps are being investigated for resistance to vibration failure and possibly as substitutes for incandescent sources in areas where lamp size is a factor; for example, thin wing sections.

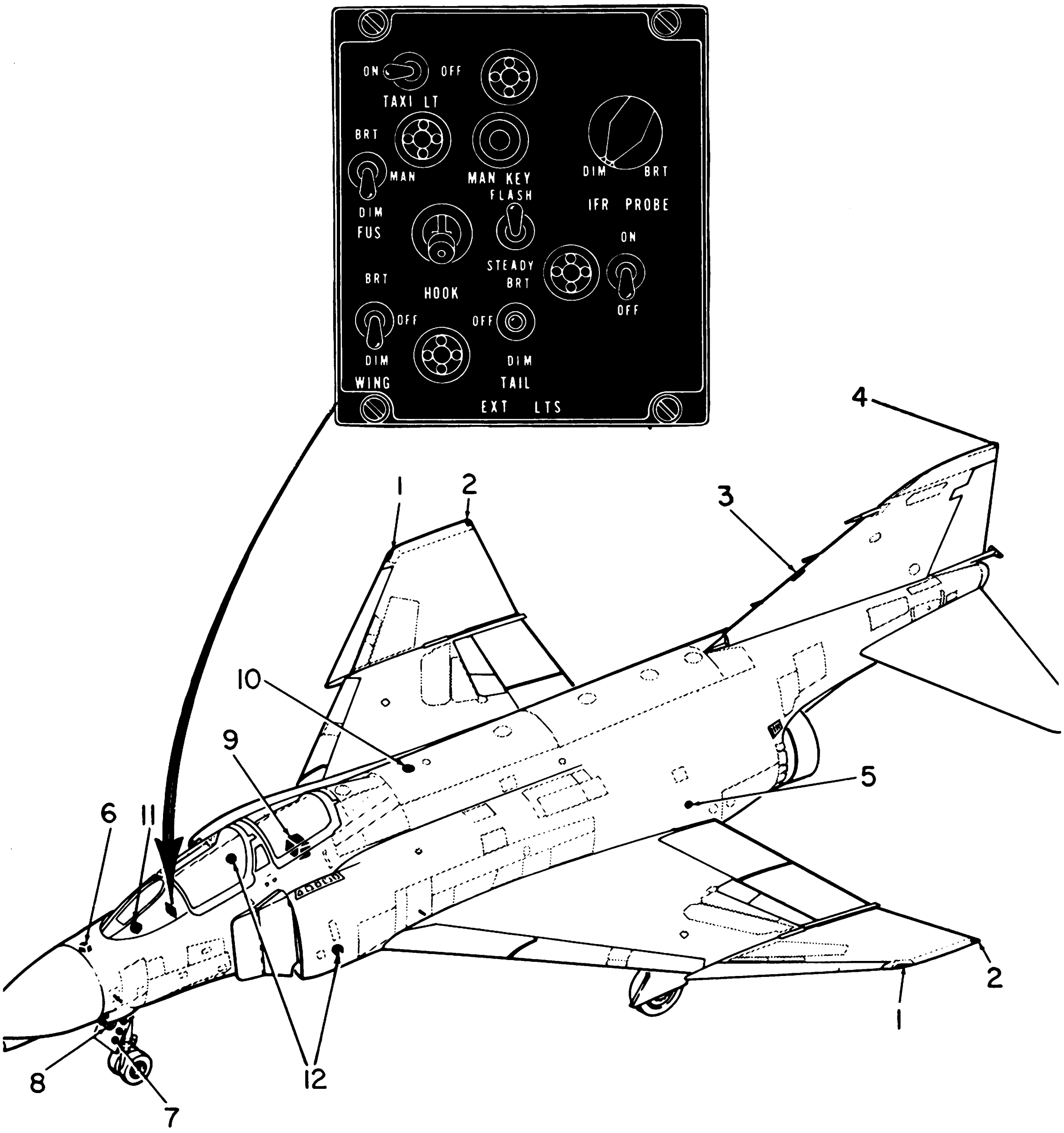
EXTERIOR LIGHTING

Numerous types of lights are used in fulfilling the exterior lighting requirements of naval aircraft. The principal types of exterior lights are the navigation or position lights, anticollision lights, landing lights, signaling lights, and formation lights.

Figure 5-4 shows the components used in the exterior lighting system of a carrier type aircraft. This figure shows the lights that are common to most naval aircraft, but it does not show every type light that may be found on different aircraft. The lighting requirements vary from one aircraft to another, depending upon the aircraft type.

NAVIGATION LIGHTS

These lights are mounted on the aircraft to attract visual attention to its position and heading



1. Wingtip position lights.
2. Join-up lights.
3. Anticollision light.
4. Tail light.
5. Angle-of-roll light.
6. Flasher.
7. Approach lights.
8. Taxi light.
9. Exterior lights relay panel.
10. Upper fuselage light.
11. IFR probe light.
12. Lower fuselage lights.

Figure 5-4.—Exterior lighting.

at night. A standard minimum set of navigation lights, meeting Federal Aviation Agency requirements for light distribution and intensity, is required on all military heavier-than-air craft.

The standard minimum set of navigation lights for night operations consists of the following:

1. One red light on the top of the left wing.
2. One green light on the top of the right wing.
3. One white light on the tail, located so as to be visible over a wide angle from the rear.
4. Anticollision lights on the top and bottom of the fuselage.

Some older aircraft are equipped with navigation lights in addition to the standard minimum set. The additional lights consist of one white light on the belly of the aircraft, one white light on the top (these are known as fuselage lights), and one yellow light on the tail. The yellow light on the tail is generally just above or to the left of the white light included in the standard minimum set, when viewed from the rear of the aircraft.

Navigation lights may burn steadily or they may flash in any one of several sequences. The rate of flashing is usually about 80 flashes per minute.

Flasher-Coder

The flasher-coder is a device used to provide two separate flashing sequences of the aircraft navigational lights. It blinks the wingtip and tail lights at approximately 80 flashes per minute. Also, it is used to provide a series of dots and dashes producing 12 coding letters for flashing the fuselage lights. The mechanism of the flasher-coder is motor operated. The flashing and coding is provided from a series of cams which actuate electrical finger contacts. From the exterior lights control panel shown in figure 5-4 you can see the various switches that may be used to cause the flasher-coder to produce certain lighting signals.

Fuselage Lights

Fuselage signal lights are mounted on the fuselage of the aircraft as a part of the navigation light system and provide a method of visual signaling. Three fuselage identification lights are installed, two on the bottom and one on the top of the fuselage. In cases where it is not practicable to install the light on the bottom, as in the case of a seaplane or of radome obstruction, two lights are installed—one on either side and as near the bottom as practicable.

Fuselage lights are used for manual coding by the pilot who has available a coding switch on the lighting control panel. These lights on some older aircraft are also automatically coded by a motor driven flasher-coder, and the pilot can select any one of 12 code letters with a selector switch which is also located on the lighting panel. Automatic coding is not provided in present production aircraft for flashing the navigation lights. Signaling is performed by a manual keying switch. Here a flasher is installed instead of the flasher-coder.

ANTICOLLISION LIGHTS

Rotary anticollision beacon lights are installed on all new aircraft and many older ones have been backfitted. Their primary purpose is flight safety, during daylight hours as well as at night.

One type anticollision light assembly consists of two 40-watt reflector type lights and a red lens assembly. The bulb assembly is rotated by a d-c motor so that approximately 80 flashes per minute occur. Electric power to the bulbs is provided by sliprings.

These lights are usually located on both the top and bottom of the fuselage; however, they may be located on other parts of the aircraft. The assembly used and its location depend upon the type aircraft.

LANDING LIGHTS

Landing lights are extremely powerful and are used to illuminate the landing strip. Multiengine aircraft usually have a landing light mounted in each wing. Single-engine aircraft use only one landing light, and it is mounted in the port wing.

Landing lights are usually of the retractable type and are actuated by a split-field series motor. The lights are of the sealed-beam type, and when in the retracted position are mounted flush with the undersurface of the wing. Some aircraft have provisions for installing a landing light in the nosewheel fairing door, while other aircraft may utilize a fixed type landing light which is mounted in the leading edge of the wing.

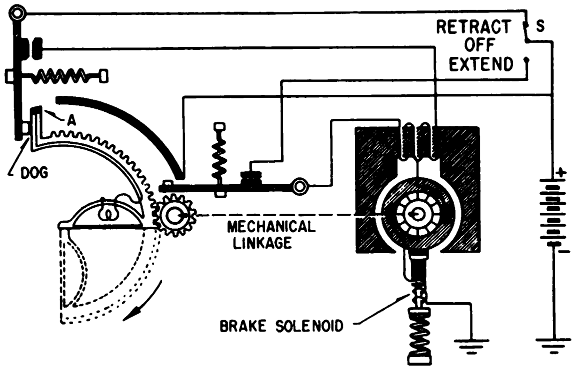


Figure 5-5.—Diagram of retractable landing light.

The principle of operation of a typical retractable landing light (fig. 5-5) is as follows: The landing light switch on the pilot's lighting panel controls the landing light motor. When the switch is positioned to either EXTEND or RETRACT, power is applied simultaneously to the magnetic brake (which releases the brake) and the drive motor. Limit switches open the motor circuit when the light has reached its limit of travel either in the up or down position. The light is stopped in any position between its travel limits by turning the switch off. When the power to the motor is turned off, either by a limit switch or the manual switch, the light is held at that particular position by the gear train.

The lamp is automatically lighted by means of a sliding contact after the light has traveled downward about 10 degrees, and will remain lighted until the lamp again reaches the 10-degree position when traveling in the upward direction. The lamp will remain lighted in any down position past the 10-degree position regardless of power application to the control motor. This arrangement provides the pilot with a means of adjusting the angle of the light beam to suit his particular needs. A switch is often provided to turn the lamp off while the light is extended.

Landing light assemblies are so designed that the maximum extended position can be varied and set for each particular aircraft installation by means of a simple adjustment. The light is set at the factory to open to an extended position of 73 degrees, plus or minus 3 degrees, with the wing surface. The light assembly, however, is capable of being extended to variable positions ranging from 50 degrees to 85 degrees from the fully retracted position.

When ground testing landing lights, caution should be exercised to prevent possible damage to the lamp.

APPROACH LIGHTS

Approach light systems are provided on carrier type aircraft for the purpose of providing the pilot and landing safety officer (LSO) with a positive indication of a safe or unsafe landing configuration. All shipboard naval aircraft have approach lights mounted in such a manner as to be clearly visible to the LSO. The installation of the approach lights varies with different aircraft; older aircraft have them mounted in the leading edge of the port wing.

Modern jet aircraft such as the F-4B and F-8E have the approach lights mounted on the nose landing gear door. A typical approach light installation for the F-4B is illustrated in figure 5-4. Most jet aircraft are equipped with a three-lamp approach light connected to the angle-of-attack indicator. The approach lights are controlled by cam actuated switches in the angle-of-attack indicator. The lights operate when all landing gears are down, when the aircraft is off the gear, and when the arresting gear is extended.

There are three lights in the approach light assembly. The lights are red, amber, and green. When the red light is on, it indicates that the angle of attack of the aircraft is low. When the green light is on, it indicates that the angle of attack of the aircraft is high. When the amber light is on, the angle of attack is optimum for the landing approach. Working in conjunction with the approach lights are the cockpit angle-of-attack indexer lights. The indexer lights present angle-of-attack information to the pilot. They are usually mounted in the cockpit on either side of the windshield so that they are clearly visible to the pilot but do not obstruct his vision.

The indexer lights are energized by cam operated switches in the angle-of-attack indicator. At very low angles of attack an inverted V is illuminated and warns the pilot to increase his angle of attack. At slightly low angles of attack both the inverted V and circular symbol (doughnut) are illuminated. At optimum angles of attack the circular symbol (doughnut) is illuminated. At very high angles of attack a V symbol is illuminated, warning the pilot to decrease his angle of attack. The indexer information corresponds with the approach lights assembly information displayed to the LSO.

The steady burning of the approach lights indicates to the LSO the angle of attack of the

aircraft, that the landing gear is down and locked, and the arresting gear is fully extended. Limit switches in the landing and arresting gear circuits are actuated when an unsafe condition exists, causing the lights to flash. If the approach lights flash, the LSO advises the pilot to check his landing and arresting gear.

An arresting gear override switch is provided for carrier landing practice at airfields. The override switch is the momentary ON type; when placed in the ON position, the arresting gear switch bypass relay is energized. When the switch is placed in the ON position, the approach lights operate only in conjunction with the landing gear since the arresting gear is not used. When power is removed from the circuit, it will automatically revert to its normal condition (arresting gear switch not bypassed). For example, in most aircraft types the circuit is restored to normal by lowering the arresting gear, by turning off the battery and generator switch, or by removing the external power. Detailed instructions on the angle-of-attack system are discussed in chapter 19 of this course.

FORMATION LIGHTS

Formation lights are used on certain naval aircraft for night formation flying. In a typical formation light installation, a wingtip formation light is installed within the upper and lower surfaces of the aft section of each wingtip. Translucent diffusing windows are installed flush with the wingtip surface above and below each light, the right-hand (starboard) light covers are green and the left-hand (port) light covers are red. The lamp assembly is bracketed to a cover plate within the lower wingtip surface, and is accessible when the cover plate is removed.

The fuselage formation lights are installed in box assemblies on each side of the fuselage. Each is equipped with a plastic window for light emission; access to the lamp is obtained by removing the box cover. These lights are connected in parallel with the wingtip formation lights; thus, they are illuminated simultaneously and are controlled from the same switches.

INTERIOR LIGHTING

The interior lighting of naval aircraft is accomplished through the use of various types of lights and lighting systems. Almost all of these may be included under one of the following types:

1. Instrument lighting.
2. Cockpit lighting.
3. Cabin and passageway lighting.
4. Boarding lights.
5. Intercommunication call lights.
6. Indicator lights.

An important consideration in connection with the interior lighting of aircraft is the fact that undue eyestrain most be prevented. The eyes are quick to make adjustments in accordance with various light intensities but this action is fatiguing and causes eyestrain. Aircraft are designed so that the lighting will produce as little discomfort as possible, and you as the person who maintains the lights should be certain that the specifications as to fixtures and lamps to be used are followed when making replacements. The following general considerations are followed in connection with the interior lighting of aircraft:

1. Lenses are used to diffuse the light if its source lies within the field of vision.
2. Bright spots of light, direct sources of light, and reflections are undesirable in low-intensity fields and are eliminated.
3. Surfaces that reflect light, such as chromium or nickel, are used sparingly.
4. Quick-change features are utilized on lighting fixtures so that lamps may be changed quickly.

INSTRUMENT LIGHTS

The first use of artificial light in aircraft was for the illumination of instruments. The operation of modern aircraft is more dependent upon the various instruments than ever before and because of this, instrument lighting becomes more important. Different methods of instrument lighting are used, and the decision as to the one best method would be a difficult one. No matter what system of lighting is used, one common requirement is that the light must not be visible outside the aircraft.

One method of lighting that was very desirable since it produced no objectionable reflections was known as indirect (mask) lighting. The lamps are set in the instrument panel and the panel is covered with a reflector (mask) which has openings in it for observing the instruments. The light is reflected back and forth until it becomes diffused and in so doing it floods the entire panel. Even though this system

produced satisfactory lighting it is impractical today because of space and weight requirements.

Another method of instrument lighting is accomplished by the installation of specially adapted shields in front of the instruments. Small lamps in small red filtered sockets are installed in the front surface of the cover shields which cast the light down and onto the instruments. These shields are cut out over the instrument for vision and are flanged in such a way as to direct the lights properly for illumination of the dial. Red light is used in naval aircraft since it has been found to be the most satisfactory of all colors for the purpose of night operations.

The intensity of light is often controlled by means of a rheostat in the lighting circuit. This is illustrated in figure 5-6. The rheostat is a variable resistor used to limit the amount of current through the circuit. When the maximum resistance has been reached, the rheostat turns off the current completely by opening the circuit. When the pivoting arm reaches the high resistance end of the rheostat, it slips off the contact surface thereby breaking the circuit. This arrangement is sometimes called a rheostat switch.

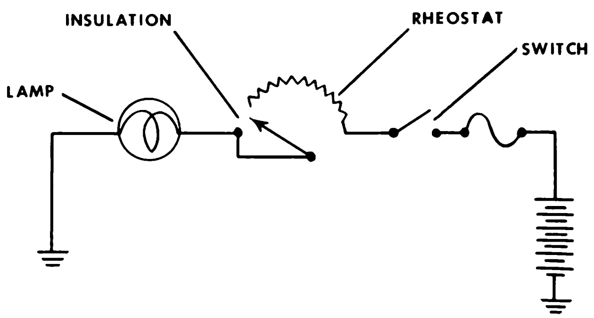


Figure 5-6.—Rheostat switch.

The present-day trend in instrument lighting is shown in figure 5-7. The lighting equipment consists of edge-lighted control panels, individual lights for the instruments on the instrument panel, and red floodlights for overall lighting. The brillance of the individual instrument lights and the red floodlights is controlled by rheostats located on the interior lights control panel. The edge-lighted panels provide diffused lighting for the control and indicator panels.

Instruments which have a light source as an integral part of the instrument are in use, and it is expected that all instruments will soon be integrally lighted. Since the use of individual lights for instruments is compatible with the "integrally lighted" instruments, they may be intermixed.

The edge-lighted control and indicator panels have a nongloss, black background with white lettering for maximum ease of reading. (See fig. 5-7 (B).) The lighting is accomplished by small lamp assemblies which are mounted so as to diffuse light through the plastic panels. These lamps are fitted with red filters to eliminate glare. All lamp assemblies in the edge-lighted panels are powered from the essential bus. Bulb replacement is relatively simple since all that is required is to unscrew the top cap from the assembly, pull the bulb from the cap, replace the bulb, and reassemble the unit.

Most of the instrument lights consist of panel lights and instrument integral lights used to illuminate the instruments. All instrument lights receive their power from the essential bus through circuit breakers, or from autotransformers through fuses. Overall light intensity is controlled by cockpit lights control panel (fig. 5-7 (B)). The INSTR PANEL lights control is a variable intensity control for the instrument lights. As the control is rotated from the OFF position in a clockwise direction, the intensity of the instrument lights increases.

The CONSOLE panel lights control is a variable intensity control for the console panel edge lights. As the control is rotated clockwise, the intensity of the console edge lights increases. Also as soon as the control is rotated from the OFF position, a switch within the control is actuated, energizing the dim contact

Nomenclature for Figure 5-7

1. Console red floodlights.
2. Instrument floodlights.
3. Spare edge lamps.
4. White floodlights.
5. Cockpit lights control panel.
6. Utility spotlight and floodlight.
7. Emergency floodlights switch.
8. Standby compass lights.

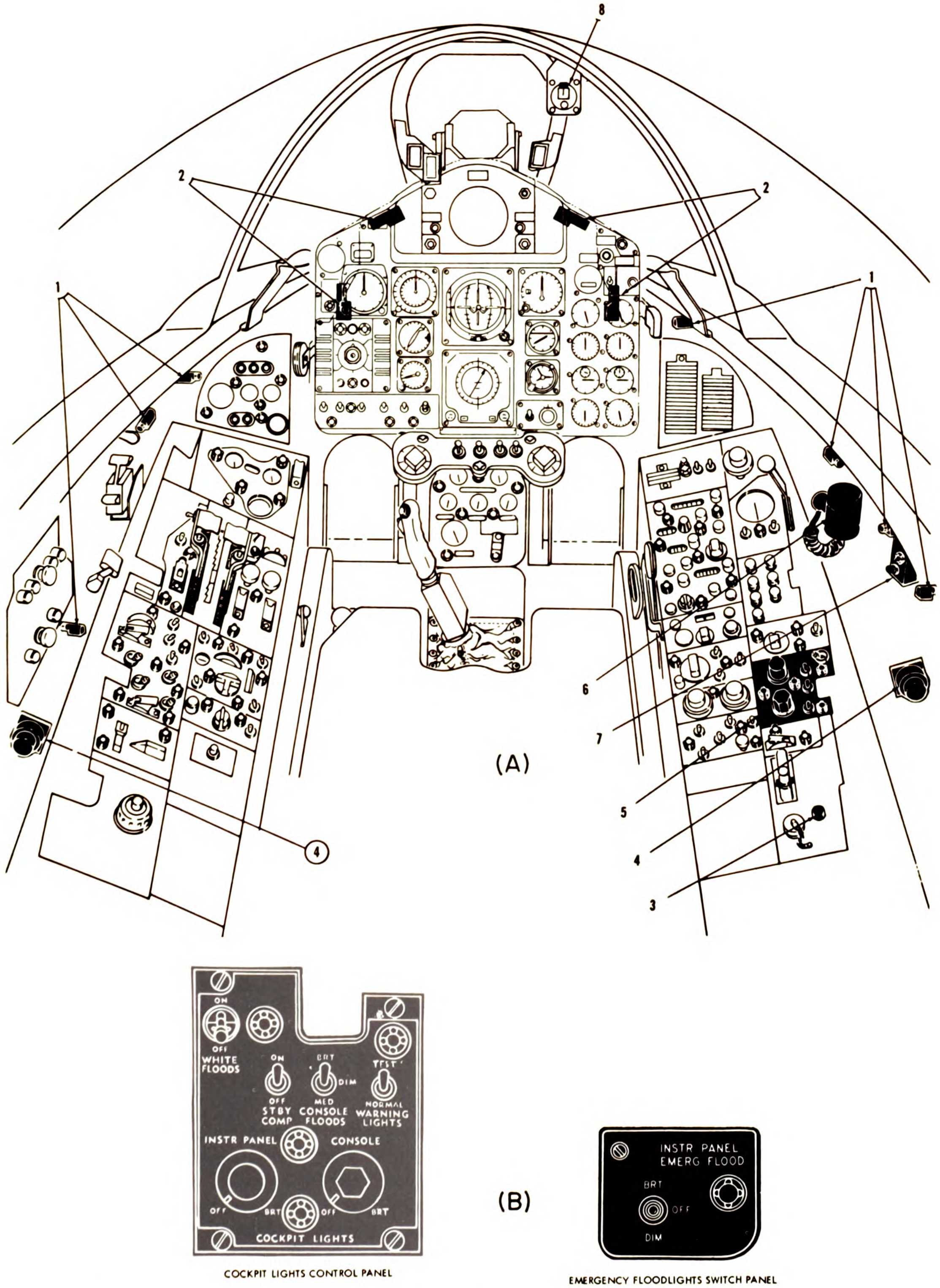


Figure 5-7 (A).—Interior and instrument lighting; (B) Emergency floodlights and cockpit lights control panels.

of the console flood switch. Therefore, the console red floodlights will operate in dim only when the console panel lights control is in a position other than OFF.

The CONSOLE FLOODS switch is a three-position switch—BRT, DIM, and MED—for selecting intensity of console floodlights. Selection of the BRT or MED position energizes the lights regardless of the position of the console panel lights control. The floodlights will remain off when the CONSOLE FLOODS switch is in the DIM position. They are energized when the CONSOLE panel lights control is rotated from the OFF position. The WHITE FLOODS switch has two positions—OFF and ON. Placing the switch to ON energizes the white floodlights. The NORMAL WARNING LIGHTS switch has two positions—NORMAL and TEST—and is spring loaded to the NORMAL position. Placing the switch in the TEST position tests all of the warning lights in the pilot's cockpit.

The INSTR PANEL EMERG FLOOD switch (fig. 5-7 (B)) has three positions—OFF, DIM, and BRT. The switch is used to illuminate the red floodlights above the main instrument panel in an emergency when the normal instrument lights are malfunctioning.

COCKPIT LIGHTING

The term cockpit lighting is rather broad in its coverage. Its meaning varies, depending on the type aircraft being described. In fighter type aircraft, it may be thought of as the interior lighting which consists mainly of individually lighted instruments and switches, lighted control panels, and necessary floodlights. In the larger aircraft, cockpit lighting includes the various lights that are required for the crew to perform its duties. It includes the interior lighting just mentioned as well as many other special lighting assemblies.

A much used lighting device is the small incandescent spotlight known as a cockpit light assembly. These assemblies, installed at crew stations, are mounted in a position where they provide illumination of the equipment which the crewmember uses during flight. The light from the lamp assembly can be focused in either a small spot or in a wide beam and minimized in amount by a red filter. Figure 5-8 shows one type light in which an ON-OFF switch and an intensity control rheostat control the operation of the light assembly. These lights are sometimes equipped with a small momentary-contact switch which, when pressed, causes the light to burn with full intensity regardless of the setting of the rheostat.

Cockpit extension light assemblies are used to provide crewmembers with an extension light for reading maps or illuminating small areas. These assemblies consist of a cable reel, switch, and lamp housing assembly. The lamp may be removed from the assembly and used as an extension light. The connecting cable which unwinds from and rewinds on a spring-actuated reel may be stopped at different positions, thereby providing a light with an adjustable cord. By adjusting the assembly, it is possible to change the size of the beam of light.

Floodlighting for the console panels is provided by a red floodlight (fig. 5-7 (A)) mounted aft and above each console panel. The brilliance of the console floodlights is controlled by a three-position switch.

CABIN AND PASSAGEWAY LIGHTS

Dome lights, adjustable extension lights, and spotlights are used for illuminating cabins and passageways. The number and types of lights that are used depend upon the type of aircraft.

Dome lights are located in the overhead or on the sides of the aircraft. These lights are not always standard throughout the aircraft and in many cases they are used for more than one purpose. The dome lighting circuits of the P-2H aircraft are briefly described as a typical example of such lighting.

The flight station dome light is installed in the overhead panel and is hinged at its forward edge so that it can be pulled down to floodlight the center stand and instrument panel. It is connected to the essential d-c bus to provide emergency flight station lighting and is not part of the regular dome lights circuit. The light switch is a three-position (OFF, RED, and WHITE) toggle type located on the center control stand.

Included in the fuselage dome lights circuit are the dome lights installed in the following locations: nose section, entrance tunnel, radarman's station, navigator's station, radioman's station, waist section, and tail section. Switches located on the copilot's switch panel give primary control of the operation of the fuselage dome lights to the copilot. None of the dome lights in the fuselage circuit can be operated until the interior lights switch has been moved away from the OFF position. The color of the illumination

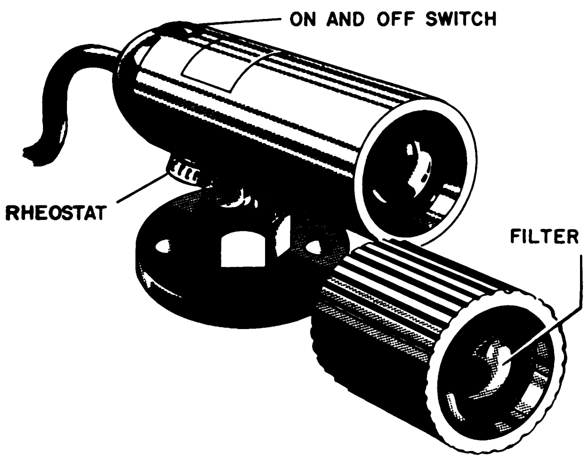


Figure 5-8.—Cockpit lamp assembly.

provided by the individual dome lights is determined by the position (RED or WHITE) of the interior lights switch at the time the individual dome light switches are actuated. The white lamp in the entrance tunnel dome light and the radarman's dome light are in the boarding lights circuit and are controlled by the boarding lights switches; the red lamps in these two dome lights are turned on or off by the dome light switch associated with the lights.

One dome light is installed in the overhead of the radar well and three dome lights are installed in the bomb bay. These lights are not part of the fuselage dome lights circuit and provide white illumination only. The bomb-bay dome lights are turned on or off automatically with the opening or closing of the bomb-bay doors; two additional switches are also provided by means of which the bomb-bay dome lights can be operated from inside the fuselage. The radar well dome light is controlled by a single ON-OFF toggle switch located on the forward bulkhead of the radar well.

Extension work lights are provided for the purpose of affording a movable source of light. This type of light was described under the heading "Cockpit Lighting." Some stations are provided with flexible work lights which may be used for special illumination. These lights provide either white or red light and are usually equipped with a rheostat type intensity control.

BOARDING LIGHTS

These lights are for the purpose of providing illumination for entering, moving through, or leaving the aircraft. The number of lights used varies from aircraft to aircraft. For example, the P-2H is provided with two boarding lights whereas the P-5B has twenty-one. Boarding lights are located throughout the aircraft and may be either white or red. In many instances boarding lights and dome lights are located in the same fixture. Typical locations for boarding lights are entrance hatches, forward compartments, electronics compartments, beaching gear compartments, and flight decks.

Boarding light circuits are usually connected in such manner that electrical power may be applied to the lights as long as the batteries are not disconnected. Many of the lights may be controlled from more than one location. In aircraft where there are a number of boarding lights, all are not connected in the same circuit. This is a safety factor; should trouble develop in some circuit all of the lights would not be affected. Some circuits are controlled by the opening and closing of hatches. When the hatch is opened the lights come on automatically and remain on as long as the hatch is kept open.

Some aircraft are equipped with intercommunication call lights. With these lights, crewmembers can signal each other. Each call light position has an indicator light and a keying switch for signaling.

INDICATOR LIGHTS

To provide a means for obtaining information pertaining to the operating status of the aircraft and its equipment, various indicator (warning) lights are installed. These lights are used for various purposes, such as indicating the position of the landing gear, arresting hook, wings, and bomb-bay doors.

Indicator lights are constructed in various shapes and sizes, dependent upon the particular job they are designed to perform. They are installed in the aircraft in such places as to be easily noticed when they are glowing. It is important that bulb replacement can be made quickly and easily since some of the lights relay vital information that concerns the safety of flight. Whenever practical, the fixtures are constructed so that the bulbs may be replaced in flight without the use of tools. Most warning lights

are so designed that a push-to-test feature enables you to determine if the bulb is good or bad. The test switch connects the bulb to the battery bus; thus the bulb's condition may be checked without actuating the equipment.

A major problem in connection with some of these lights is the control of their brightness. They must be bright enough to be seen during daylight operation but not so bright at night as to cause undue eyestrain. Brilliance control is obtained by connecting resistors in the lighting circuit, placing dimmer caps on the lights, special adaptation of edge lighting, and special type lenses in which dimming can be obtained by twisting the lens.

An example of the use of indicator lights is the system used to indicate the locked position of aircraft wings. Low travel limit switches, which are used to control the lights, are mechanically connected to the lockpin on each wing. If the wings are in the unlocked position, current flows to a warning light. The light is extinguished only when the wings are locked in place.

Another application of the use of an indicator light is the landing gear unlocked warning light. For example, in some aircraft, a red light in the translucent handle of the landing gear control lever glows when the gear is not locked in the up or down position.

One other typical application is the arresting hook warning light. In the S-2A aircraft the light forms an integral part of the arresting hook handle and is controlled by the arresting hook control handle switch and the hook operated switch. When the arresting hook handle is placed in the down position, a circuit is completed from the primary bus to the warning light through the normally closed contacts of the hook control handle switch and the hook operated switch. The warning light remains on until the hook is fully extended, at which time the hook operated switch is actuated; this opens the circuit and extinguishes the light.

HELICOPTER LIGHTING

Figure 5-9 shows the lights that are installed on a typical helicopter. Refer to this figure when studying the material that follows. Lighting provisions include lights for navigation, signaling, warning, inspection, and interior lights for general and specific lighting. The lights operate from the 28-volt d-c power distribution system.

EXTERIOR LIGHTS

Exterior lights include navigation and signal lights, a controllable spotlight, rotating beacon anticollision lights, hover lights, and floodlights. Operation of the exterior lights is controlled by switches on the overhead control panel and pilot's collective pitch control stick.

The navigation and signal lights consist of the side position lights (10) and the tail position light (7). The side position lights consist of a red position light mounted on the outboard side of the left sponson, and a green position light mounted on the outboard side of the right sponson. The tail position light is a white position light mounted on the pylon.

The controllable spotlight (14), which is located in the bottom forward fuselage structure, may be extended, retracted, or rotated. The spotlight is controlled by the ON, OFF, and RETRACT switches, located in a box at the forward end of the pilot's control stick. A spring-loaded four-way thumb switch, marked EXTEND, RETRACT, LEFT, RIGHT, operates the controllable spotlight. With the switch in the ON position, the spotlight may be extended or retracted to any position, and rotated 360 degrees either right or left by moving the four-way thumb switch in the appropriate direction.

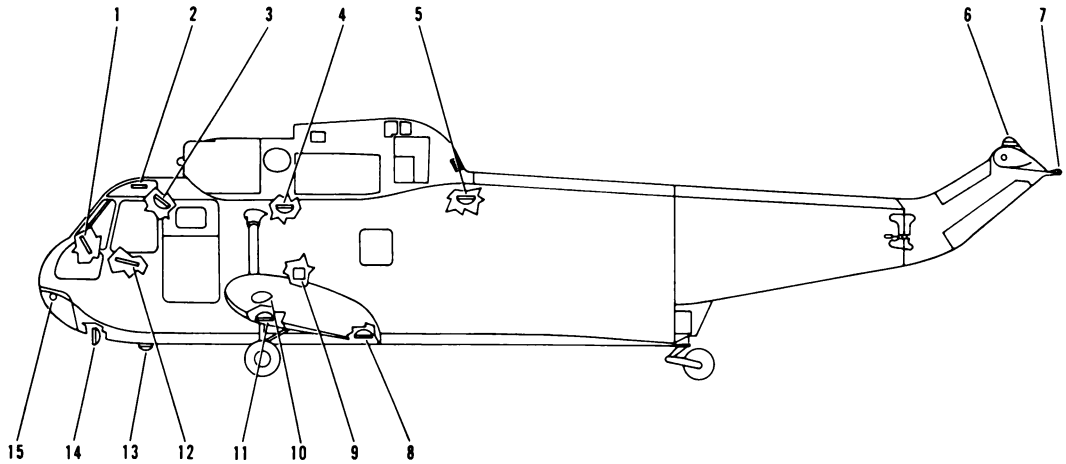
Rotating beacon and anticollision lights (6 and 13) are installed on the forward fuselage bottom structure and on the fairing on top of the pylon. These lights are controlled by the BEACON OFF ANTICOLL switch on the overhead control panel. With the switch in the BEACON position, the lights operate with full power; in the ANTICOLL position, the lights are dimmed by the resistors in the circuit.

One hover light is located forward under the left wing and the other hover light is located on the bottom aft section of the right sponson. These lights (8 and 11) operate simultaneously with the floodlights when the switch on the cyclic pitch lever is in the position marked HOVER LTS.

Two floodlights (15) are located in the electronics compartment door. The floodlights operate when the FLOOD LTS, OFF, HOVER LTS switch is in the position marked FLOOD LTS, or simultaneously with the hover lights when in the HOVER LTS position.

INTERIOR LIGHTS

Interior lights include dome lights and spotlights, console and panel lighting, instrument



1. Instrument lights.
2. Spotlight.
3. Dome light.
4. Dome light.
5. Dome light.
6. Anticollision light.
7. Tail position light.
8. Hover light.
9. Sonar panel lights.
10. Side position lights.
11. Hover light.
12. Control panel lights.
13. Anticollision light.
14. Controllable spotlight.
15. Floodlights.

Figure 5-9.—Typical helicopter lighting.

lights, sonar operator's lights, and inspection lights.

Dome lights (3, 4, and 5) are provided for interior lighting—one in the cockpit and two in the cabin. The lights contain a white lamp and a red lamp. They are controlled by dome light switches marked CABIN CKPT RED, OFF, AND WHITE. The dome light switches are located on the overhead control panel. A spotlight (2) with an extension cord is mounted on each side of the overhead control panel and is controlled by a switch on the light itself.

Shielded console and control panel lights (12) controlled by a combination power switch and dimming rheostat, illuminate the radio console, the pilot's control panel, and the copilot's control panel. The lights are controlled by the CONSOLE and PANEL LTS knob, located on the overhead panel in the cockpit. The sonar panel lights (9) are located on the sonar operator's console. The lights are controlled by the CONSOLE LTS, DIM, BRT rheostat, located on the side of the sonar operator's console. The hoist and hover trim panel lights, located on their respective panels, are also controlled by this rheostat.

Shielded instrument lights (1) are provided for all instruments. The flight instrument lights and nonflight instrument lights are controlled by appropriately marked knobs on the overhead switch panel, which control both power switches and dimming rheostats. The red bulb in the cockpit dome light is also an emergency instrument light, and is controlled by the INSTRUMENT EMER LTS control knob, located on the overhead switch panel.

Sonar operator's lights are provided to illuminate the sonar well. The lights are controlled by the WINCH LT, ON, OFF switch, located on the sonar operator's panel.

SPECIAL PURPOSE LIGHTS

JOIN-UP LIGHTS

The join-up lights are mounted on the trailing edge of the wingtips, one on each wing. The light on the left wing is red in color, and the light on the right wing is green. The join-up lights are controlled by both the EXT. lights master switch and the wing lights switch. The join-up lights are shown in figure 5-4.

IN-FLIGHT REFUELING PROBE LIGHT

Most modern high performance naval aircraft flights are limited due to fuel capacity. To increase range and flight time, in-flight refueling became necessary both night and day. Most naval shipboard aircraft have provisions for in-flight refueling. During night refueling, it became necessary to install in-flight refueling probe lights (IFR). The IFR probe light is installed on the fuselage forward of the IFR probe. The light lens is usually red in color and is used during night in-flight refueling operations to illuminate the refueling probe and drogue from the refueling aircraft. Figure 5-4 shows a typical IFR probe light installation.

ANGLE-OF-ROLL LIGHT

The angle-of-roll light is located on the left side of the fuselage near the trailing edge of the wing. (See fig. 5-4.)

The angle-of-roll light is on at the same time as the approach lights.

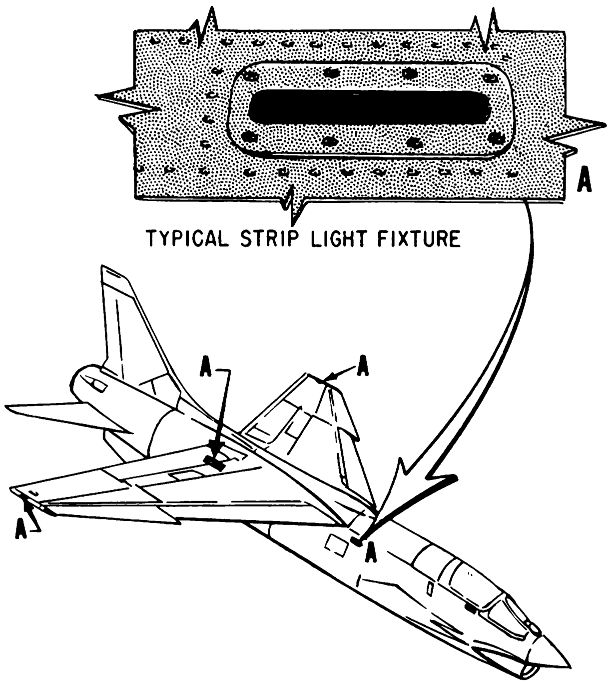


Figure 5-10.—Strip light installation.

STRIP LIGHTS

Some modern naval aircraft employ strip lighting. Strip lights consist of wing strip lights and fuselage strip lights. One wing strip light assembly is installed in each wingtip. The lights are mirror images. The left-hand lights assembly lens is red in color while the right-hand light is green. The fuselage strip lights consist of four identical lights which are installed on the fuselage—two on the forward fuselage (left- and right-hand sides), and two on the aft fuselage (left- and right-hand sides). All fuselage strip lights are equipped with yellow lens.

The strip lights are controlled by a toggle switch located on the exterior lights control panel. Switch positions are DIM, OFF, and BRT. Placing the switch in BRT connects a-c bus power to stepdown transformers which supply the strip light lamps with operating power. Placing the switch in DIM connects a-c power thru a dimming resistor connected in series with the stepdown transformer for light dimming. Figure 5-10 shows a typical strip light installation.

ANCHOR LIGHTS

Anchor lights are installed on all aircraft equipped for water landings and are used when the aircraft is anchored at night. These lights are white and are located near the nose, wing, and tail tips of the aircraft.

They are controlled through a two-way switch arrangement; one switch is on the pilot's console and the other on the outside of the aircraft. The outside switch is usually near an entrance hatch and is accessible from a small boat. Either switch may be used to operate the lights. Anchor lights receive their power directly from the battery bus; thus, it is not necessary to actuate any switch other than the anchor light switch in order to turn them on. When they are on, an indicator light on the pilot's console panel will also be lighted. Figure 5-11 shows a typical anchor light circuit.

TAXI LIGHTS

Taxi lights are used after an aircraft has landed to aid the pilot in maneuvering. On aircraft having a nosewheel, the taxi light assembly is usually located on the movable strut, so that the light will turn with the wheel. It is always installed so as to afford maximum visibility for the pilot and copilot. (See fig. 5-4 for a typical taxi light installation.)

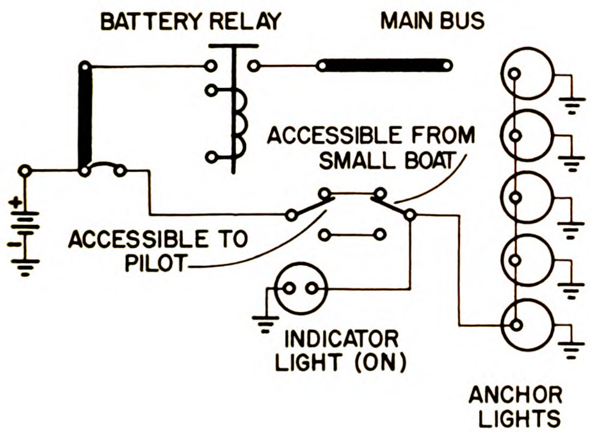


Figure 5-11.—Anchor light circuit.

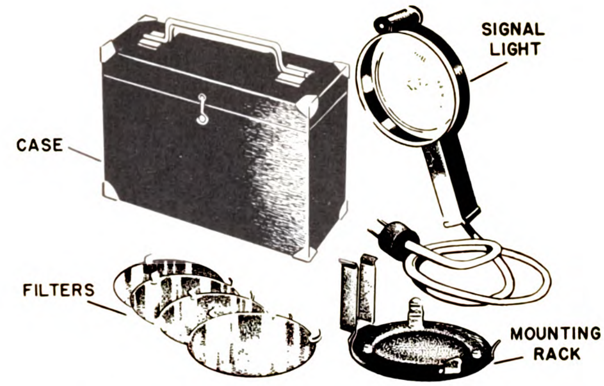


Figure 5-12.—Signal light, filters, and case.

PORTABLE SIGNAL LIGHT

The signal light shown in figure 5-12 is used for aircraft-to-aircraft and aircraft-to-ground communication. It is carried in a case accessible to the pilot or copilot or mounted in a nearby rack. The lamp is a sealed beam signaling type designed for fast cooling of the filaments. It is operated with red, green, amber, or neutral (for night operation) filters for identification purposes. It is operated by means of a trigger type switch mounted in a pistol grip handle with the light beam directed by means of sights.

MAINTENANCE AND INSPECTION

Maintaining light circuits consists mainly of replacing burned out lamps and fuses, and inspecting wires, circuit breakers, and connections.

The length of time that many exterior lights can safely burn during ground checks is very critical since the heat that is generated may damage the lighting assembly. This is due to insufficient heat dissipation since there is no appreciable movement of air around the assembly. For example, on some aircraft, ground operation of the wingtip lights must be limited to about 15 minutes. If operation is necessary beyond this limit, either allow a cooling period between each operation or provide an airblast.

One of the major problems of lighting fixtures is corrosion. Such conditions as salt spray and a salt-laden atmosphere cause rapid deterioration of fixtures. Unless metallic surfaces are protected by plating or similar noncorrosive surface, rapid corrosion may result. Fungus is a problem in hot, humid environments and usually takes the form of mildew and rot decay. Fungus growth can be easily eliminated by proper cleaning with available solvents.

Cloudy lamp lenses and reflectors are usually signs of air leaks around the lens. When relative humidity is excessive, it becomes a major problem and may cause electrical breakdowns. A high humidity, coupled with temperature fluctuations with periods of wetting and drying, causes physical distortion, decomposition, electrolysis, electromechanical corrosion, and cracks and fusion.

When inspecting lamps and lighting fixtures, necessary steps must be taken to combat corrosion. Use sealants and gaskets on all lighting assemblies and fixtures that require them. Keep all lamp lenses and reflectors clean and highly polished. When replacing burned out lamps and/or lighting assemblies, replacement parts which are identical in all respects with the original must be used. This will insure proper service and long life.

When performing any inspection, maintenance, or corrosion control action, consult the Maintenance Instructions Manual for the specific aircraft type.

CHAPTER 6

AIRCRAFT STORAGE BATTERIES

The function of the aircraft storage battery is to provide an emergency source of electrical power for operating the electrical systems of an aircraft. The battery also functions in such a manner that it eliminates the commutator ripple produced by the d-c generator. During normal aircraft operation, the generator supplies the primary source of electrical energy, and maintains the battery in a charged state. The battery supplies power to the aircraft only when the speed of the engine or generator drive system becomes so slow that the generator's output voltage falls below the battery voltage.

The battery is the emergency power source for the aircraft. For this reason, extreme care must be taken to see that every precaution is made to maintain the battery in perfect condition. Therefore, the battery should never be used for starting engines or servicing equipment if another source of power is available. Such unnecessary usage tends to shorten the life of the battery and keeps the battery in poor condition to meet emergency operation requirements. During the periods when the engines are idling or being started, the electrical load should be kept at a minimum. The service life of the aircraft battery depends a great deal upon the frequency and quality of care it is given. Batteries that are abused or that receive careless treatment and servicing generally have their service life ended prematurely.

LEAD-ACID BATTERIES

The most common aircraft battery in use today is the lead-acid type. However, two recent types, which are known as the nickel-cadmium and the silver-zinc batteries, are being used in some aircraft. These batteries are described later in this chapter.

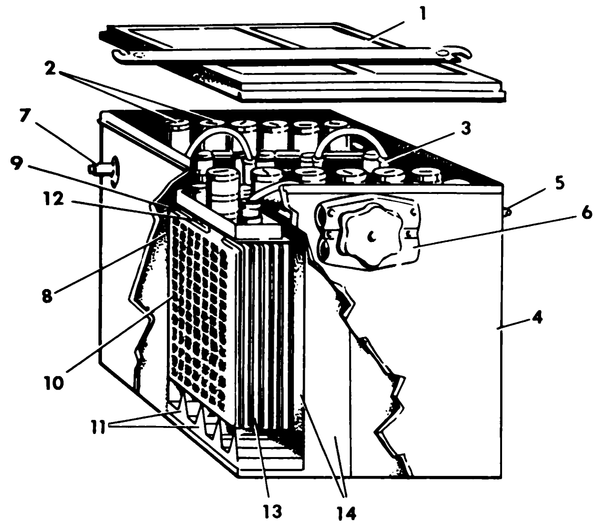
Fundamentally, there is no difference in the operation of the lead-acid aircraft battery and the lead-acid automobile battery. Both types of batteries have their plates immersed in a solution of sulfuric acid and water and operate on the same basic principles. The basic principles of the lead-acid battery are covered in detail in the chapter entitled "Batteries" in Basic Electricity, NavPers 10086-A.

Aircraft batteries require a great deal more care than automobile batteries because of the unusual conditions under which they operate. The aircraft battery is usually shielded by enclosing it in a grounded, metal housing. (See fig. 6-1.) This completely shields the battery and the terminal connections. This shielding eliminates to a large degree radiofrequency inference from being induced into the communication system from the battery and its associated components.

Most aircraft batteries are equipped with a quick-disconnect unit as shown in figure 6-1. This unit is a heavy-duty connector with a handle attached to a threaded post. The battery cables can be disconnected from the battery posts simply by turning the handle and pulling the quick-disconnect unit.

Aircraft batteries are built so that they will not leak even when the aircraft is flying upside down. This is made possible through the use of "nonspill" vent plugs (caps) which contain a valve that is operated by a balanced lead weight. The valve is normally open; but when the plug is tilted through a wide angle or inverted, the weight closes the valve.

Since it is important to keep their weight at a minimum, aircraft batteries have a small capacity. Consequently, they must be used and serviced with great care. For example, if connected to a charging voltage that is too high, an aircraft battery will overcharge in a short time. This overcharging may cause premature loosening of the active material on the plates. When a battery is being charged, a portion of the energy is dissipated in the electrolysis of



1. Metal cover.
2. Filler cap and vent plug.
3. Cell connectors.
4. Metal container.
5. Vent.
6. Quick-disconnect receptacle and plug.
7. Vent.
8. Cell container.
9. Positive plate group strap.
10. Plate.
11. Plate supports.
12. Negative plate group strap.
13. Separators.
14. Cells.

Figure 6-1.—Typical aircraft lead-acid storage battery.

the water in the electrolyte. Thus, hydrogen is released at the negative plates and oxygen at the positive plates. These gases bubble up through the electrolyte and collect in the airspace at the top of the cell. If violent gassing occurs when the battery is first placed on charge, the charging rate is too high. (NOTE: The rate should never be so high that violent gassing occurs.) If the rate is not too high, steady gassing, which develops as the charging proceeds, indicates that the battery is nearing a fully charged condition. A mixture of hydrogen and air can be dangerously explosive. Smoking, electric sparks, or open flames should not be permitted near charging batteries.

INSPECTION AND MAINTENANCE

The battery container and cover are cast from aluminum alloy. Inspect the container for abrasions, dents, cracks, and corrosion. Battery covers should be inspected for the condition of cover gaskets and proper fitting of the cover. Excessive corrosion should be brushed off with a stiff fiber brush. Then, with the vent plugs securely in place, flush the top of the battery and container with a water-and-soda solution, exercising caution to prevent the solution from getting into the cells. The soda (an alkali) neutralizes the acid. Complete the cleaning of the battery by flushing the area with fresh water or wiping cloths saturated with fresh water until all the alkali salts have been removed, preventing any corrosive action from this source. After cleaning, always make sure that the escape holes in the vent plugs are clear and the weight valve is operating properly.

Inspect the mounting bolts, and be sure they are snug enough to hold the battery securely in place without putting too much strain on the case. Too much pressure may cause the sealing compound to crack or may warp the container or cover, permitting leakage of acid. If evidence of leakage is found, the battery should be replaced.

Check the specific gravity with a hydrometer to determine how much additional energy is still available from the battery. This test will indicate the percentage of acid in the electrolyte, as this percentage varies with the state of charge and the corresponding specific gravity of the electrolyte. In order to be accurate, all specific gravity readings should be corrected to a standard temperature of 80° F from the temperature of the observed electrolyte. (Checking the battery with a hydrometer and correcting for temperature differences are explained later in this chapter.) Recharge the battery if the temperature-corrected specific gravity is below 1.240.

Daily Inspections

These inspections require specific gravity measurements in at least two cells, and inspection of the battery for visible evidence of any unsatisfactory condition. Daily inspection should be made prior to the usual tests of the electrical equipment in the aircraft and engine runup prior to flight of the aircraft. Remove the battery from the aircraft when any of the following occurs:

1. Specific gravity is below 1.240 (corrected for temperature).
2. Electrolyte level is too low to obtain specific gravity readings.
3. Accumulation of electrolyte on top of the cells.

4. Corrosion exists on the battery terminals or inside the metal container.

When it is necessary to add water to a battery, use distilled water. Clean drinking water may be used only if distilled water is not available. There is no need to add water if the electrolyte level is three-eights inch above the plates in a fully charged battery and the specific gravity readings can be taken with a hydrometer. If it is necessary to add water, use only enough to bring the electrolyte approximately three-eights inch above the plates. The addition of too much water is just as detrimental to the battery as an insufficient amount. Too much water will cause the electrolyte to bubble out of the vents. This will not only weaken the strength of the electrolyte, but will also corrode the battery.

Intermediate Checks

Even though no abnormal condition is observed, a battery should be removed from the aircraft and serviced every 60 days and during a major inspection. Servicing consists primarily of the following battery capacity tests:

1. Give the battery an equalizing charge.
2. Determine that specific gravities are within the range of 1.275 to 1.300 near the end of the charge.
3. Discharge the battery at the 2-hour rate of 21 volts for a 24-volt battery.

Reject any battery which fails to give 2 hours operation at a battery temperature of 70° F or higher.

A battery will also require removal and recharge if left in an unused aircraft for a period of one week or more, depending upon temperature. A fully charged battery will lose approximately one-half of its charge in the following number of days for the temperature given:

60° F	90 days
80° F	45 days
100° F	14 days
120° F	9 days

Insulation breakdown between battery terminal and case occurs often as a result of cracked insulation washers and sleeving of terminal feedthroughs. This can be attributed to excessive tightening of the terminal securing jamnuts and the presence of acid at this point through a fault in the acid-resistant plastic coating and bituminous cell sealing compound.

Ventilation and sumps in lead-acid aircraft batteries are provided by openings at each end which can be used for venting or draining. Several holes are also provided in the cover for venting purposes. When batteries are delivered, both the cover and the side venting holes are sealed. In installations where a vent-sump system is not incorporated, the side venting holes are left sealed. In this case, the cover holes are opened to provide the necessary ventilation for the escaping gases. When a vent-sump system is used it should be inspected periodically.

In a vent system (fig. 6-2 (A)), the void above the cells and beneath the sealed cover is subjected to differential pressure areas on the skin of the aircraft through the vent nozzles level with the top of the cells on opposing sides of the battery container. As the battery is mounted in the aircraft, the highest of the two vent nozzles is connected to a rising vent tube which is exposed to a positive pressure area on the skin of the aircraft. This provides definite pressure on the battery in flight and acts as a chimney or flue for the light hydrogen gas when the aircraft is at rest. The lower of the two vent nozzles connects to a tube which is exposed to a negative pressure area on the skin of the aircraft and is physically lower than the battery vent nozzle.

When a battery drain sump is used (fig. 6-2 (B)), the discharge tube from the battery is connected to a glass jar sump and extends into the jar approximately 1 inch. The exhaust tube (from the sump jar), the end of which is cut off at a 30-degree angle and extends into the sump jar approximately one-third its depth, is routed to the skin surface of the aircraft. The sump jar contains a chemically treated absorbent material for neutralizing gases and excess battery solution.

When a sump jar is not used (fig. 6-2 (A)), the exhaust tube is connected to the nozzle of the battery, which is lowest when the aircraft is in a taxiing position, and is located in such a manner that battery acid may escape without injury to the aircraft.

Refer to the Maintenance Instructions Manual of the aircraft for specific directions concerning the maintenance of the particular vent-sump system that is used.

Cold Weather Operation
and Maintenance

Recharge time is especially important in cold weather operations. At low temperatures the internal resistance of a battery is so high that the charging current drawn from a 27.7-volt aircraft electrical system is relatively small.

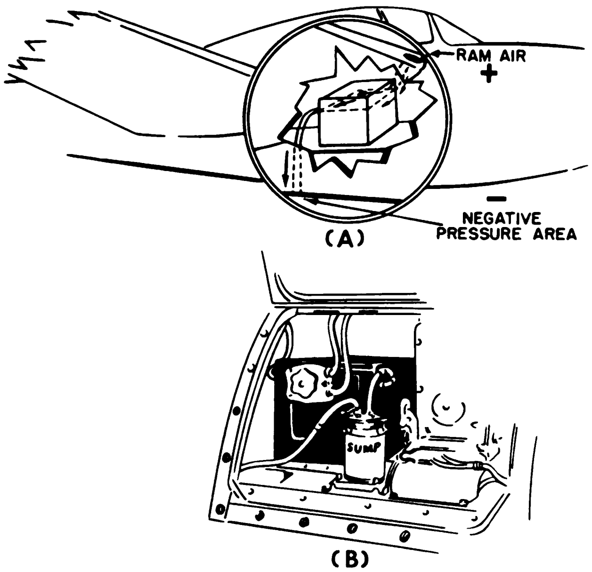


Figure 6-2.—Battery vent system.

Therefore, at low temperatures the battery charging rate is such that during a given flight the battery will usually not fully recharge.

When operating at temperatures of 0° F or below, batteries should be maintained at a fully charged level of 1.280 in order to avoid decreased efficiency due to a low charging rate. Batteries should be kept above 32° F whenever possible. Below -20° F, it is almost impossible to recharge a battery in flight.

Battery freezing may be attributed to a discharged battery, or water being added and the battery not placed on charge immediately. The relationship of specific gravity of the electrolyte to its freezing point is given in table 6-1. It is important that water never be added in freezing weather when batteries are to be left standing before charging. About a half-hour charge will mix the water with the electrolyte. A leaking cell may result from adding water to a battery, which then freezes. If the electrolyte becomes frozen, it is always necessary to replace the battery although, in case of partial freezing, thawing in a warm room may save it. However, it should be thoroughly checked before being used in an aircraft.

Table 6-1.—Battery freezing points.

Specific gravity	Freezing points degrees F.
1.300	-95°
1.275	-80°
1.250	-61°
1.225	-35°
1.200	-17°
1.175	- 4°
1.150	+ 5°
1.125	+13°
1.100	+18°
1.050	+26°
1.000 (water)	+32°

When an aircraft located in below zero temperatures is not in use, its battery should be removed and kept in as warm a place as possible, or heated in the aircraft. Do not attempt to keep the battery warm by charging, as continued overcharging is detrimental to its life.

Commissioning a Battery

New batteries are shipped and stored without electrolyte in them, but with the plates dry-charged. Dry lead-acid batteries are to be filled with a solution of sulfuric acid having a specific gravity as recommended by the battery manufacturer. Specific gravity should be approximately 1.275, but this may differ in accordance with the manufacturer's instructions.

To add electrolyte to a battery, fill each cell with electrolyte prepared to the proper specific gravity, usually 1.275. The temperature of the electrolyte used should never exceed 90° F. Fill the battery to three-eights inch above the protectors on top of the separators. Allow the battery to stand at least 1 hour after filling with electrolyte. If the level has fallen, add more electrolyte to restore it and replace the vent plugs. If electrolyte is spilled on the battery, it should be removed with a soda solution, being careful not to allow the solution to get into the cells. The battery should then be flushed with fresh water.

If time permits after a new dry-charged battery has been filled, it should be given an initial charge in accordance with instructions furnished by the manufacturer. In the absence of instructions, the first charge should be given at the finishing rate stated on the battery nameplate. This charge should be continued until the voltage and specific gravities of all cells show no

increase over a period of 2 hours. If the temperature of the battery exceeds 100° F, the charge should be stopped until the temperature falls below 100° F.

Usually no adjustment of the specific gravity is necessary, but if it should exceed 1.300 in any cell, it should be reduced to some value between 1.275 and 1.300. The specific gravity can be reduced by removing some electrolyte with a hydrometer syringe and replacing it with distilled or clean drinking water.

When it is necessary to mix electrolyte, 1 part of concentrated acid should be mixed with 2 3/4 parts of distilled or clean drinking water by volume. Mixing should be done in a lead-lined tank. Glass or earthenware vessels may crack by the heat generated. After the electrolyte has cooled to about room temperature, stir it thoroughly and measure the specific gravity. This specific gravity may then be adjusted to the desired value by adding small amounts of water or acid as required.

CAUTION: When mixing electrolyte, wear goggles, rubber gloves, and a rubber apron. Always pour the acid very carefully and very slowly into the water while stirring the solution. Never pour water into concentrated acid because heat will be generated so rapidly that the solution may be thrown violently from the container. Sulfuric acid will destroy clothing and may cause severe skin burns. If any acid is splashed into the eyes or on the skin, it should be immediately flushed with liberal quantities of water and baking soda (sodium bicarbonate). (If baking soda is not immediately available, flush freely with water.) Report immediately to the nearest medical facility for further treatment. For safety and convenience, each battery shop should keep a supply of 5 to 10 percent solution of sodium bicarbonate constantly available in the shop. Such a solution may be made by mixing water and sodium bicarbonate, one-half pound to each gallon of water.

Battery Test

A specific gravity test is made with a hydrometer which indicates the state of charge. If the location of the battery permits, hold the hydrometer in a vertical position and leave the hose inserted in the cell while making the test. If the battery is located so that this is impossible, hold the hydrometer horizontally while it is filling, then pinch the hose just above the cell cover and remove the hydrometer to a position where it can be held vertically while reading. Be sure that the float is not sticking to the side of the syringe. When filling the hydrometer, draw in just enough electrolyte to raise the float from the plug upon which it normally rests. Always return the electrolyte to the cell from which it was removed.

The temperature of the battery in any test is important and must be measured with a thermometer and recorded with the results of the test. The mercury bulb of the thermometer must be completely immersed in the electrolyte to give an accurate reading. The specific gravity of a battery changes with battery temperature. Therefore, a standard test temperature of 80° F has been adopted. When the specific gravity is measured at some other temperature, the value can be corrected to a standard temperature by adding or subtracting as necessary. The correction is 0.004 (4 points) for each 10° F difference from the standard temperature. This is added when the temperature for the measurement is higher, or subtracted when the temperature is lower than the standard temperature. Specific gravity corrections are not usually necessary for temperatures from 70° to 90° F, but for the lower temperatures they may become increasingly important. For example, an observed specific gravity of 1.280 at 30° F would be only 1.260 when corrected to 80° F, revealing that the battery is not fully charged. If a reading of 1.265 was observed at 120° F, the corrected value would be 1.281. In this case, the battery is fully charged.

A high-rate discharge test is sometimes used to indicate the internal condition of battery cells. This test is accomplished by measuring the terminal voltage of a cell while under appreciable load.

The terminal voltage is affected by both the resistance of the external load and the internal resistance of the cell. This high-rate discharge test, therefore, consists only of a comparison between voltage reading of the cell under test and other good cells of equal capacity.

The high-rate discharge tester consists of two heavy prongs bridged by a heavy nichrome shunt of low resistance. A voltmeter is connected across this shunt. (See fig. 6-3.)

The battery should be fully charged before the tester is used. Push the ends of the prongs into the ends of the terminal posts of the cell to be tested. The heavy current which passes through the nichrome shunt simulates normal load current. Hold the prongs in firm contact with the cell terminal posts for about 15 seconds.

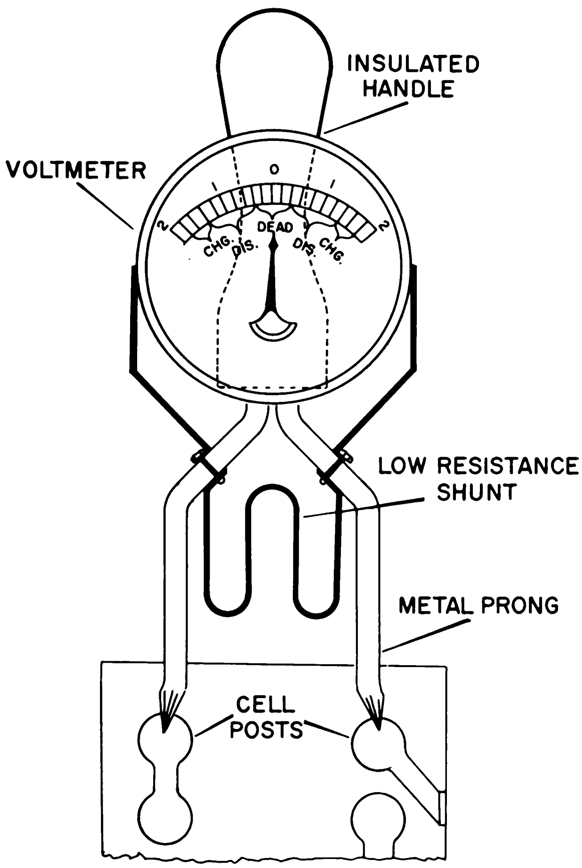


Figure 6-3.—High-rate discharge tester.

The voltage should remain constant. Compare the readings obtained with the average readings of cells that are of equal capacity, fully charged, and in good condition. All readings must be made with the same tester. If any cell of a battery shows a voltage less than about 0.2 volt below the average reading of good cells, it is unfit for service.

Storage and Disposal

New batteries without electrolyte (dry-charged batteries) may be stored as received from the manufacturer in locations not subject to abnormally moist atmospheric conditions for long periods of time without detrimental effect. The negative plates, however, undergo slow oxidation, causing a corresponding loss of charge. This requires a longer charging time, commensurate with the age of the battery, when the battery is being commissioned.

New batteries containing electrolyte, and those that have been in service and are still serviceable, should be stored in as cool a location as possible. These batteries should be given a recharge once each month if the ambient temperature is below 80° F, and every 2 weeks if the temperature is above 80° F. Recharging is necessary because idle batteries tend to discharge, and should always be kept in a fully charged condition. Self-discharge occurs much more rapidly at high temperature. In the section "Intermediate Checks," there is a listing that shows the number of days in which a fully charged battery will lose half its charge at various temperatures.

Repaired batteries should not be used in aircraft except in extreme emergencies or where new batteries are not available. Batteries which are no longer fit for service in aircraft should be painted bright yellow and stenciled on two sides with black letters: DO NOT INSTALL IN AIRCRAFT—FOR GROUND USE ONLY. These batteries may then be used on testing devices, battery carts, or other equipment. Batteries known to be completely unserviceable should be returned to the station battery shop for salvage. The formal survey of batteries is performed by an established battery shop only.

NICKEL-CADMIUM BATTERIES

Some nickel-cadmium batteries used in naval aircraft are physically and electrically interchangeable with the lead-acid type, while some are sealed units which use standard plug and receptacle connections which are used on other electrical components. These batteries generally require less maintenance throughout their service life in regard to the adding of electrolyte or water than lead-acid batteries.

The nickel-cadmium and lead-acid batteries (fig. 6-4) have capacities that are comparable at normal discharge rates, but at high discharge rates the nickel-cadmium batteries have higher capacities. Physically, the lead-acid battery is comprised of 12 cells with a nominal cell voltage of 2 volts, while the nickel-cadmium battery contains 20 cells with a nominal voltage of 1.3 volts per cell.

MS25210 and MS25211 lead-acid batteries are equipped with the same quick-disconnect receptacle and plug used on nickel-cadmium batteries. The nickel-cadmium batteries are enclosed in a solid case.

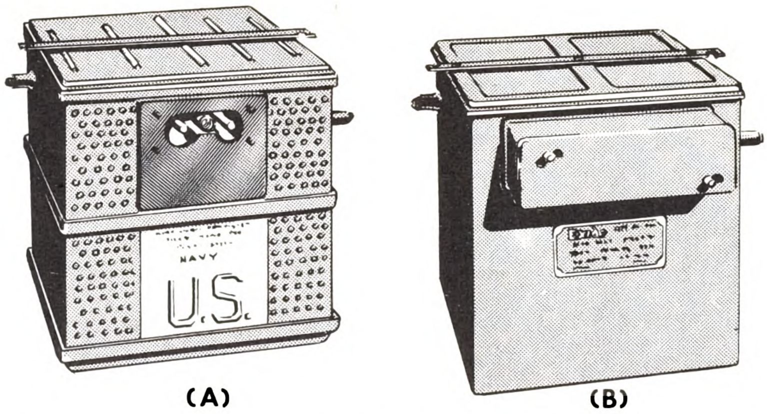


Figure 6-4.—(A) Nickel-cadmium battery; (B) lead-acid battery.

Final distinction of the lead-acid battery from the nickel-cadmium or the silver-zinc battery should be accomplished from the MS number on the nameplate of each battery, and not by appearance.

The lead-acid battery contains sulfuric acid solution (H_2SO_4) for the electrolyte, while the nickel-cadmium and the silver-zinc batteries utilize potassium hydroxide (KOH). Unlike the lead-acid type, the nickel-cadmium battery does not require any venting provisions under normal conditions. Nickel and cadmium are used as the electrodes. The active material on the negative plate is cadmium oxide. When charging current is applied, this material gradually loses its oxygen and becomes metallic cadmium. The active material of the positive plate is nickel oxide. This is brought to a higher state of oxidation by the charging current. As long as charging continues, these changes take place until both materials are completely converted. The electrolyte in a nickel-cadmium battery does not enter into any chemical reaction with either the positive or negative plates. It acts only as a conductor of current between them and there is no significant change in specific gravity regardless of the state of charge. Because the electrolyte is a conductor only, there is no flaking or shedding of active materials from the plates as in lead-acid batteries. No external vent system is required since gassing of this type battery is practically negligible.

As a safety precaution, however, relief valves have been installed in the negative posts (old type) or in the fill hole cap of each cell (fig. 6-5) in order to release any excess gas that is formed when the battery is charged improperly.

DETERMINATION OF THE STATE OF CHARGE

At the present time there is no quick method of accurately measuring the state of charge of a nickel-cadmium battery. In an aircraft, the only practical method is to measure the open circuit battery voltage. A charged battery should have an open circuit voltage of 26.0 volts or more, while a discharged battery will normally measure 25.0 volts or less. A precision type voltmeter should be used for taking these measurements.

In a battery shop, either of two methods may be used for determining the state of charge of a nickel-cadmium battery; namely, the constant potential method or the discharge method. The constant potential method consists of connecting a constant potential of 28.5 ± 0.3 volts across the battery and observing the charging current. If the current falls to 4 amperes or less within 5 minutes, the battery is charged.

The discharge method consists of placing a 15-ampere load across the battery for 5 minutes. If the voltage does not drop below 22 volts during the discharge period, the battery may be returned to service after being recharged.

MAINTENANCE

Charging

Nickel-cadmium batteries should preferably be charged at an ambient temperature of 70° to

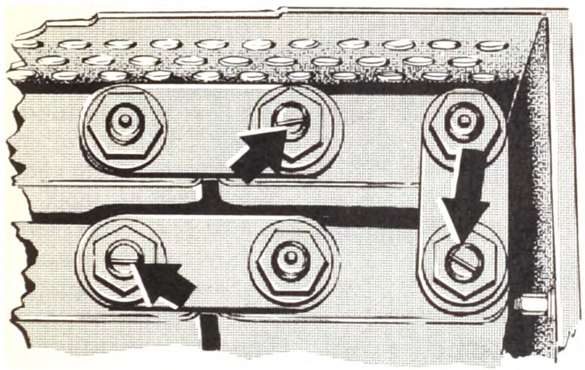


Figure 6-5.—Relief valves in negative post of cells.

80° F. Never allow a battery on charge to exceed 100° F as this may cause overcharging and gassing. In the battery shop a thermometer should be placed between the central cells in such a manner that the bulb of the thermometer is located below the top of the cell. Whenever the temperature of a battery is 100° F or higher, the battery should not be charged.

The rate of charging of a nickel-cadmium battery is dependent upon two factors, the first being the charging voltage, and the second being the temperature of the battery. In hot weather where the ground air temperature approaches 90° F or higher, the battery can be adequately charged at 27 volts. In mild ground air temperatures ranging from 35° to 85° F, the battery can be satisfactorily charged at 27.5 volts. In cold, subfreezing weather the battery requires a charging voltage of 28.5 volts.

In order to secure maximum electrical capacity of the battery for any emergency during flight, it is essential that the voltage regulators on the aircraft be adjusted to compensate for climatic temperature variations.

The voltage changes should be seasonal and depend on the average ground air temperatures. CAUTION: Certain equipments utilizing electron tubes are adversely affected by high d-c input voltages. Settings of voltage regulators should be kept to a minimum consistent with satisfactory battery charging. Consult the Maintenance Instructions Manual for specific voltage regulator settings for a particular aircraft.

The nickel-cadmium battery was designed and constructed to operate without gassing of the cells. The charging voltage should be maintained below the gassing voltage (approximately 29.4 volts at 80° F) so that the life of the battery is prolonged. Therefore, on constant potential charging in the battery shop, the voltage should be set at 28 volts or less. Under no circumstances should this voltage exceed 28.5 volts.

If the battery has never been placed in service, follow the manufacturer's instructions accompanying the battery for the initial charge. If possible, the battery should be charged by the constant potential method.

For constant potential charging, maintain the battery at 28 volts for 4 hours, or until the current drops below 3 amperes. Do not allow battery temperature to exceed 100° F.

For constant current charging, start the charge at 10 to 15 amperes and continue until the voltage reaches 28.5 volts—then reduce the current to 4 amperes and continue charging until the battery voltage reaches 28.5 volts, or until the battery temperature exceeds 100° F and the voltage begins to decline.

General Maintenance

Since these batteries contain sealed cells, maintenance is not required as frequently as is the case with lead-acid batteries. However, personnel performing periodic inspections should check very closely for potassium carbonate deposits (white and crystalline) at points of cell joints and at the cell terminal post nuts. The appearance of such deposits would be an indication of electrolyte leakage. The electrolyte level should be checked at every major aircraft inspection. The relief valves located in the negative post or fill hole cap of each cell (fig. 6-5) should be kept clean at all times. Clean the battery periodically with compressed air; and be sure to keep the relief valves free of any encrustations or carbonate which may form. Wipe the connections and terminals and grease slightly with pure vaseline. Every precaution should be taken to keep the battery as dry and moisture free as possible at all times. Never wash the battery with water.

Removal From Service and Disposition

Any battery that contains expanded or bulged cells, broken retaining grids, or broken or

cracked containers should be immediately removed from service. Any of the following conditions are just cause for removing a battery from service:

1. Any battery that has an open circuit voltage of less than 25.0 volts within 24 hours after a full charge.
2. Any battery which contains cells whose open circuit voltage is not uniform within 0.2 volt.
3. Any battery which fails to produce 30 amperes for an hour when it is discharged at a 30-ampere rate to a cutoff voltage of 18.0 volts.

Batteries which have been removed from service for any of these failures are to be disposed of in accordance with current BuWeps directives. Nickel-cadmium batteries may be stored in any state of charge without damage or deterioration. Fully charged batteries will retain a large portion of their charge for a year or more if the ambient temperature does not exceed approximately 90° F. The loss of charge increases as temperature increases; therefore, storage should be in a cool location.

Electrical Leakage to Case

If electrical leakage from either terminal to the case exceeds 3 volts, conduct a capacity test as previously described. If the cells of the battery are uniform within 0.2 volt and if, when the battery is discharged at a 30-ampere rate, it provides 30 ampere-hours or more, return the battery to service after recharging. Batteries not meeting these requirements will be returned to supply for disposition.

SAFETY PRECAUTIONS

The electrolyte used in these batteries is potassium hydroxide (KOH). This is a highly corrosive alkaline solution, and should be handled with the same degree of caution as sulfuric acid (H_2SO_4). If KOH is sprayed on any material, wash it immediately with liberal quantities of water and neutralize the affected area with vinegar or a weak solution of acetic acid.

CAUTION: If KOH touches the skin, wash the affected area thoroughly with liberal quantities of fresh water and neutralize with vinegar, lemon juice, or a weak (5 percent) solution of acetic acid. If the face or eyes are affected, treat as above and report immediately for medical examination and treatment.

SILVER-ZINC BATTERIES

Silver-zinc batteries are used largely in military applications and in some industrial applications where their unique characteristics are sufficiently important to justify their comparatively high cost. These batteries are currently installed in various models of Navy helicopters.

The silver-zinc battery (fig. 6-6) was developed for one major and one secondary purpose. The major purpose was to secure a large quantity of electrical power for both ground and emergency flight operations. The secondary purpose was to permit a design weight savings in new aircraft. A lightweight, silver-zinc battery provides as much electrical capacity as a much larger lead-acid or nickel-cadmium battery.

Operational silver-zinc batteries have a nominal operating voltage of 24 volts, obtained with sixteen 1.5-volt cells. Cell electrolytic levels do not have to be monitored, nor is the addition of water necessary throughout the life of the cells. The only required operations that might be considered maintenance are the normal recharging of the battery and keeping the top surfaces of the cells reasonably clean.

OPERATION

The construction and electrochemical reactions of the silver-zinc battery are somewhat similar to those of the nickel-cadmium type. When in the fully charged condition, the positive plates are composed of silver oxide and the negative plates of zinc. As the battery discharges, the positive plates are reduced to metallic silver and the negative plates are oxidized. Thus, when the battery is discharging, electrons are flowing out of the cathode (negative plates) and into the anode (positive plates) by way of the external circuit.

The electrolyte, potassium hydroxide in aqueous solution, exists as potassium (K) and hydroxide (OH) ions, which serve only to conduct the electric charge between the plates. Thus, the electronic or metallic conduction in the external circuit is balanced by the ionic or electrolytic conduction through the electrolyte, so as to maintain the net charge transfer into and out of each electrode the same.

As with other types of alkaline cells, and unlike lead-acid cells, the electrolyte does not take part in the chemical transformations and therefore its specific gravity does not change

Figure 6-6.—Silver-zinc battery.

with the state of charge of the cell. As long as the plates are covered, the battery's electrical capacity is independent of the amount of electrolyte present.

CHARACTERISTICS

Because of its extremely low internal resistance, the silver-zinc battery is capable of discharge rates of up to 30 times its ampere-hour rating. The low internal resistance (as low as 0.0003 ohms per cell) is due primarily to the excellent conductivity of its plates, the close plate spacing (possible because small amounts of electrolyte may be used successfully), and the fact that the composition (and therefore the conductivity) of the electrolyte does not change during discharge. The internal conductivity of the battery increases during discharge as the positive plates are changed from oxides of silver (fair conductors) to metallic silver.

The battery's high electrical capacity per unit of space and weight is a result of the close plate spacing, the large degree to which the active plate materials are utilized, and the absence of heavy supporting grids in the plate. Silver-zinc batteries are capable of producing as much as six times more energy per unit of weight and volume than other types. Silver-zinc cells have

been built with capacities ranging from tenths of ampere-hours to thousands of ampere-hours.

Good voltage regulation is provided by the relatively constant voltage discharge characteristic of the silver-zinc battery. Terminal voltage is essentially constant throughout most of the discharge when discharged at rates higher than the 2- or 3-hour rate.

Silver-zinc batteries have a maximum service cycle life which is less than that of other types, but their life expectancy compares favorably with that of other types of batteries that are designed for maximum capacity per unit of space and weight such as nickel-cadmium.

MAINTENANCE AND TESTING

In general, silver-zinc batteries require maintenance which is similar in many respects to that which is required of the lead-acid type batteries. Testing the battery's open circuit voltage is the method by which you will ascertain its state of charge.

A silver-zinc battery tester (fig. 6-7) or a voltmeter which reads accurately to 0.1 volt should be used to test the open circuit voltage of the battery. If the reading is below 25.6 volts, remove the battery cover and inspect the top of the battery for corrosion or damaged cells. If any damage is evident, remove and replace the battery.

Corrosion may be removed by wiping with a damp cloth. After all connections have been inspected and tightened, recheck the open circuit voltage. If the reading is still below 25.6 volts, check each cell voltage with the tester or voltmeter. Readings between 1.83 volts and 1.86 volts per cell will indicate that the battery is charged to at least 70 percent of its capacity. If the reading on any cell is below 1.83 volts, remove the battery from the aircraft.

If one or more cells read 1.60 volts or lower, while the others give higher readings, the battery has become unbalanced. The cause for this unbalance is usually an excessively high discharge rate. If this condition is left uncorrected, this unbalance on subsequent discharges will probably lead to cell reversal and battery failure. To correct this unbalanced condition, it is necessary to drain (discharge) the cells individually to 0 volts at a 10-ampere-hour or lower rate. The battery should then be recharged using a silver-zinc battery charger and the constant current method. The constant current method (charging at a 4-ampere rate) provides the quickest and best means of achieving and monitoring a normal input. In an emergency, a constant potential source may be used, with a rheostat connected in series to limit initial current surges to 50 amperes or less, providing the charge is monitored so as not to exceed 28 volts.

Silver-zinc batteries are sensitive to excessive voltage during charging and may be damaged if the voltage exceed 2.05 volts per cell. Precaution must therefore be taken to insure that the charging equipment is adjusted accurately to cut off the current at 28.7 volts.

Where charging is not monitored automatically or periodically, a voltage cutoff system must be used which will interrupt the charging current when the voltage rises to 28.7 volts.

If possible, charging should be performed at an ambient temperature of 60° to 80° F, and the battery temperature during charging should not exceed 150° F as measured at the intercell connections.

Silver-zinc batteries do not generate any harmful gases during normal charge; however, the colored cell vent valve should be removed from the vent hole during charging. If electrolyte is forced from the vent hole, it is an indication of overheating, and the charging should be interrupted for 8 hours. After charging, the batteries should be allowed to stand idle at least 8 hours.

The electrolyte level of the batteries should be adjusted periodically. The level in each cell of the battery is adjusted by either removing excess electrolyte or adding distilled water. Refer to the Maintenance Instructions Manual for the applicable aircraft for the proper electrolyte leveling procedures.

The safety precautions relating to silver-zinc batteries are the same as those which have been presented for the nickel-cadmium batteries.

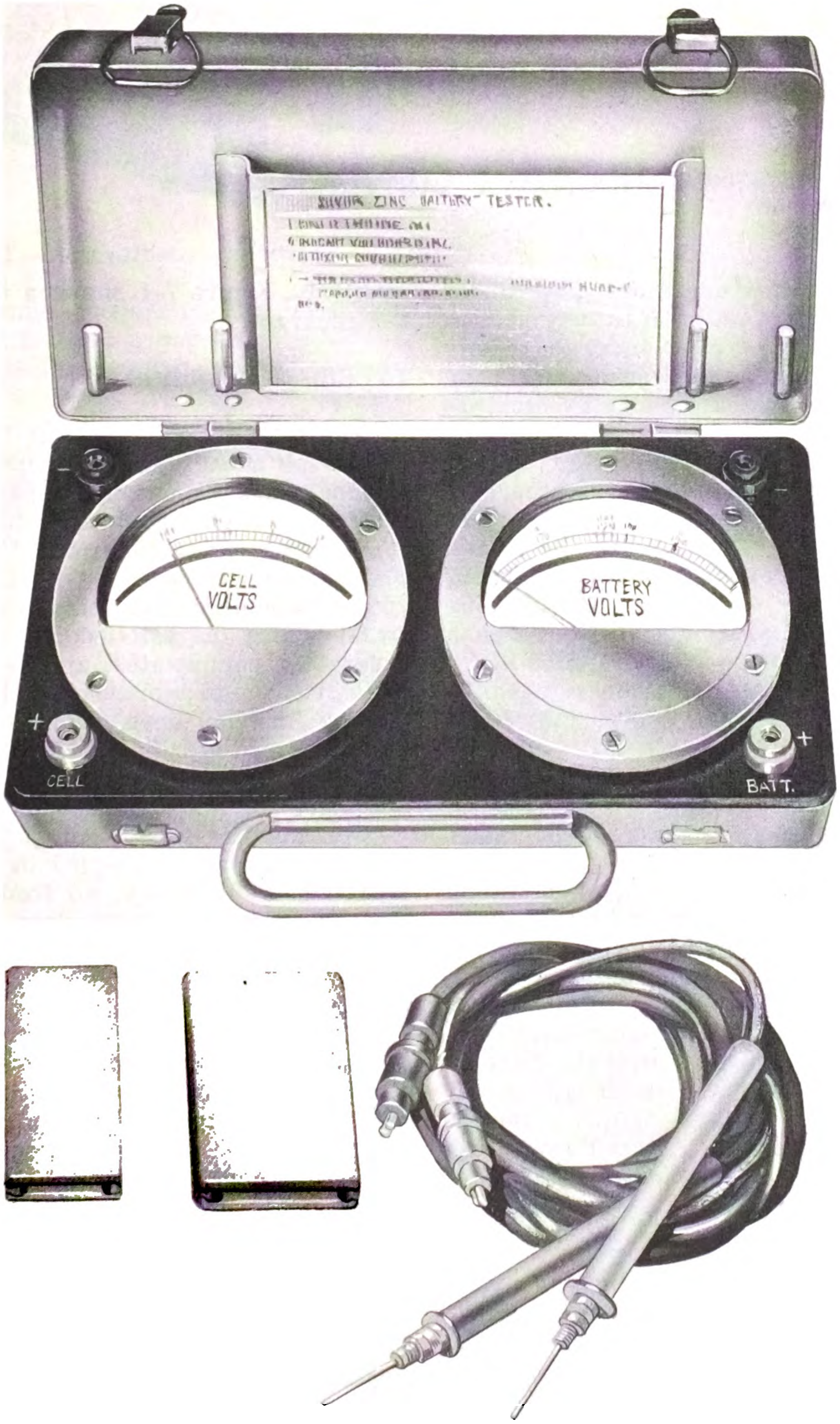


Figure 6-7.—Silver-Zinc Battery Tester, Model RAC777.

CHAPTER 7

AIRCRAFT GENERATORS

Energy for the operation of most electrically operated equipment in an aircraft depends upon electrical energy supplied by a generator. A generator is a machine that converts mechanical energy into electrical energy by electromagnetic induction. A generator which produces alternating-current energy is called an a-c generator. One which produces direct-current energy is called a d-c generator. Either type, however, operates by the induction of an a-c voltage in coils as a result of varying the amount and direction of the magnetic flux threading through the coils. The major difference between an a-c generator and a d-c generator is in the method by which the electrical energy is collected and applied to the external circuit. For a detailed discussion of a-c and d-c generator theory refer to Basic Electricity, NavPers 10086-A.

In aircraft using direct-current electrical systems, the d-c generator is the regular source of electrical energy. One or more d-c generators driven by the engine in the aircraft supply electrical energy for the operation of all d-c equipment in the electrical system and energy for charging the battery. The number of generators is determined by the power requirement of a particular aircraft. In most aircraft, there is only one generator driven by each engine. In some large aircraft, there are two generators on a single engine. Aircraft employing alternating-current systems depend mainly upon electrical energy supplied by a-c generators. Aircraft a-c generators are discussed later in this chapter.

D-C GENERATORS

Generators used in naval aircraft differ somewhat in design, for they are built by a number of manufacturers. All, however, have the same general construction and operate similarly. Figure 7-1 shows a typical aircraft d-c generator.

TYPES AND RATINGS

The most common aircraft d-c generator is the 28-volt shunt type machine; that is, the field windings are connected in parallel with the armature. High-output generators also employ commutating poles (interpoles) and compensating windings. These are employed to produce good commutation (minimize brush sparking) by counteracting the self-induced emf in the coil undergoing commutation and by opposing field distortion due to armature reaction. The magnetic field from these windings does not add to that produced by the shunt-field winding for producing output voltage; thus these generators are not classified as compound generators.

Commutating-pole windings and compensating windings are connected in series with the load (fig. 7-2); hence, all load current flows through them. These windings are series elements of the generator's output circuit.

Current Range

Shunt generators for aircraft are designed for a wide range of current capacities. Generators used on basic type training aircraft and light observation and reconnaissance aircraft, which have a minimum of electrical equipment, sometimes use generators rated as low as 50 amperes. Large attack aircraft, patrol aircraft, and transports use generators rated as high as 500 amperes. Some types of aircraft contain so much electrical equipment that they require more than one generator in order to supply enough current for the load. It is not uncommon to find two or more shunt generators mounted on one aircraft.

The use of more than one generator on an aircraft provides a safety factor. Should one

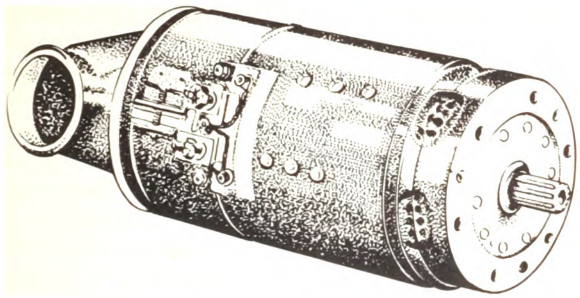


Figure 7-1.—Aircraft d-c generator.

generator become inoperative the electrical system will still have a source of generator power. In the multigenerator aircraft the normal electrical demands are such that the generators are loaded considerably below their maximum capacity. This allows near normal operation in case one of the generators fails since the others can absorb the load and still not be overloaded.

Speed Range

Aircraft generators are designed to operate within different speed ranges. The speed range is that range of speed in which a generator must be operated in order to obtain rated generator output; that is, rated voltage at all values of load current within the current range of the generator. The low-speed range is approximately 2,000 to 4,500 rpm and the high-speed range is approximately 3,000 to 8,000 rpm. Either end of these ranges may vary slightly, depending on the design of a particular generator. Some generators are designed to operate at an upper speed range as high as 10,000 rpm.

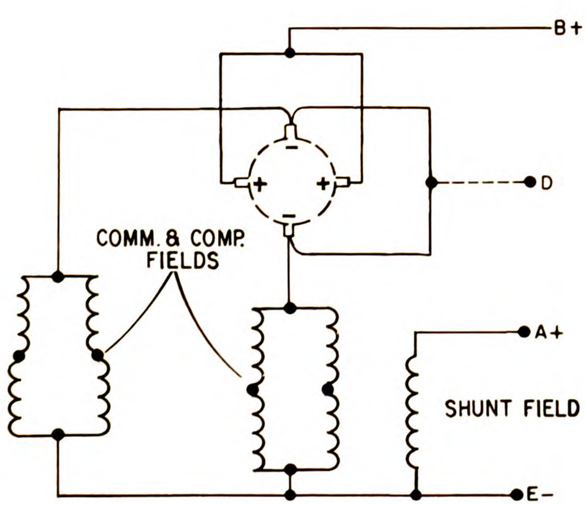


Figure 7-2.—Internal electrical connection of a shunt generator.

A-C/D-C Generators

The trend in modern aircraft is toward a-c electrical equipment. This necessitates having a source of alternating current. On aircraft that require a large capacity of a-c power, separate a-c generators are used. On aircraft that require only a small amount of a-c power, rather than have two separate generators, the two generators are combined in one housing. This is known as a combination a-c/d-c generator. The direct-current rating of this type generator usually ranges from 25 to 200 amperes. These combination generators are designed either as low-speed or high-speed machines. The a-c section of this generator is discussed later in this chapter.

D-C Exciters for A-C Generators

All generators, both d.c. and a.c., need direct current to excite the field coils. In an a-c generator containing no d-c section capable of supplying an external d-c load, provisions must be made to supply the a-c generator with d-c excitation. This may be accomplished by providing a small d-c generator in the same housing with the a-c generator or by a small external d-c generator not in the same housing with the a-c generator.

This external exciter may be mounted on one end of the a-c generator shaft, thereby being driven by the same prime mover which turns the a-c generator, or it may be mounted separately and driven by some other prime mover. In all cases, the purpose of the exciter is to supply excitation for the field windings of the a-c generator.

The a-c generators used on aircraft have a self-contained exciter. The voltage of this exciter is approximately 28 volts and the current rating is such that it can withstand continuous, maximum current drain to the field coils of the a-c generator. The exciter generator is quite small in comparison to a regular generator, since the only load it supplies is its own field windings and the field windings of the a-c generator.

BASIS FOR D-C GENERATOR RANGES

The speed range of a generator is governed by the output voltage desired. The speed at which the generator will have to turn to produce this particular output voltage depends on its electrical design. Since power is equal to E times I, the power rating of a generator is determined by the voltage of the generator times the current capacity. The current capacity of a generator is determined by the size of the armature conductor, the type of winding on the armature, and the efficiency of the generator cooling system. Power rating is expressed as continuous or overload.

The continuous rating is the amount of power (current) which the generator can deliver indefinitely with proper cooling without injury to the generator. The overload rating is the amount of power which the generator can deliver for short periods of time. This overload rating is usually expressed as a percentage of the continuous rating and time is expressed in minutes. Example: 150 percent for 2 minutes in regards to a generator rated at 200 amps would mean that 300 amps of current could safely be withdrawn from the generator for a period of 2 minutes.

The continuous duty rating of high-speed, engine-driven generators is given for a speed of 6,000 rpm. Sustained operation at higher speeds requires derating (decreased output).

FACTORS AFFECTING GENERATOR POWER RATINGS

A high-speed generator can produce more power for a given size than a low-speed machine. This is possible since less wire in series is necessary to produce a given voltage in the high-speed generator. Since a shorter length of wire is necessary, a larger size wire can be used, thus increasing the current capacity of the generator.

Due to the large amounts of current which aircraft generators deliver, cooling becomes a major problem. Aircraft generators are cooled by blast air directed through the generator. The higher the altitude at which the aircraft is operating, the more difficult it is to cool the generator because of the rarefied condition of the atmosphere at high altitudes. The amount of heat which a given volume of air can remove from a generator is determined by the density of the air; the less the density, the less the heat removed. If the temperature of the generator is allowed to rise too high, the insulation may be damaged.

The voltage, current rating, and speed range of aircraft generators are usually found on a metal nameplate secured to the generator frame. If this information cannot be found on the generator, it can be found in the manufacturer's manual, BuWeps publication for that particular generator, or tables that are frequently given in the Digest of U. S. Naval Aviation Electronics.

GENERATOR CONSTRUCTION

Figure 7-3 is an exploded view of a typical aircraft d-c generator. The generator is designed with shunt, commutating, and compensating fields placed upon the four main field poles and the four commutating poles which are equally spaced around the edge of the generator frame. The armature core consists of iron punchings stacked and secured on the outer shaft. The armature coils, wrapped in bands of binding wire, are located in the lengthwise slots in the core and are held in place by wedges. The ends of the coils are connected to the commutator which is keyed to and pressed on the hollow outer shaft. The entire assembly (less the inner shaft and commutator) is coated with insulating varnish.

The inner shaft and damper assembly is inserted into the outer shaft. It drives the outer shaft by means of the commutator-end splines which fit tightly into mating grooves on the inside of the outer shaft. A locking device prevents any axial motion of the inner shaft which may be caused by engine vibration. The inner shaft is a flexible drive spindle which absorbs the unsteady driving force from the engine. The friction damper is used to damp twisting oscillations, thereby reducing spline wear and preventing spindle breakage.

The field assembly consists of a field frame and welded mounting flange; four main field poles with shunt-field coils and compensating-field coils; four commutating poles with commutating-field coils; and a terminal block. The shunt-field coils surround the main poles, and the compensating-field coils are wound in slots in the main poles. The commutating-field coils are wound around the commutating poles. The entire assembly is coated with insulating varnish. The field assembly is connected to the brush rigging assembly by two positive and two negative field leads.

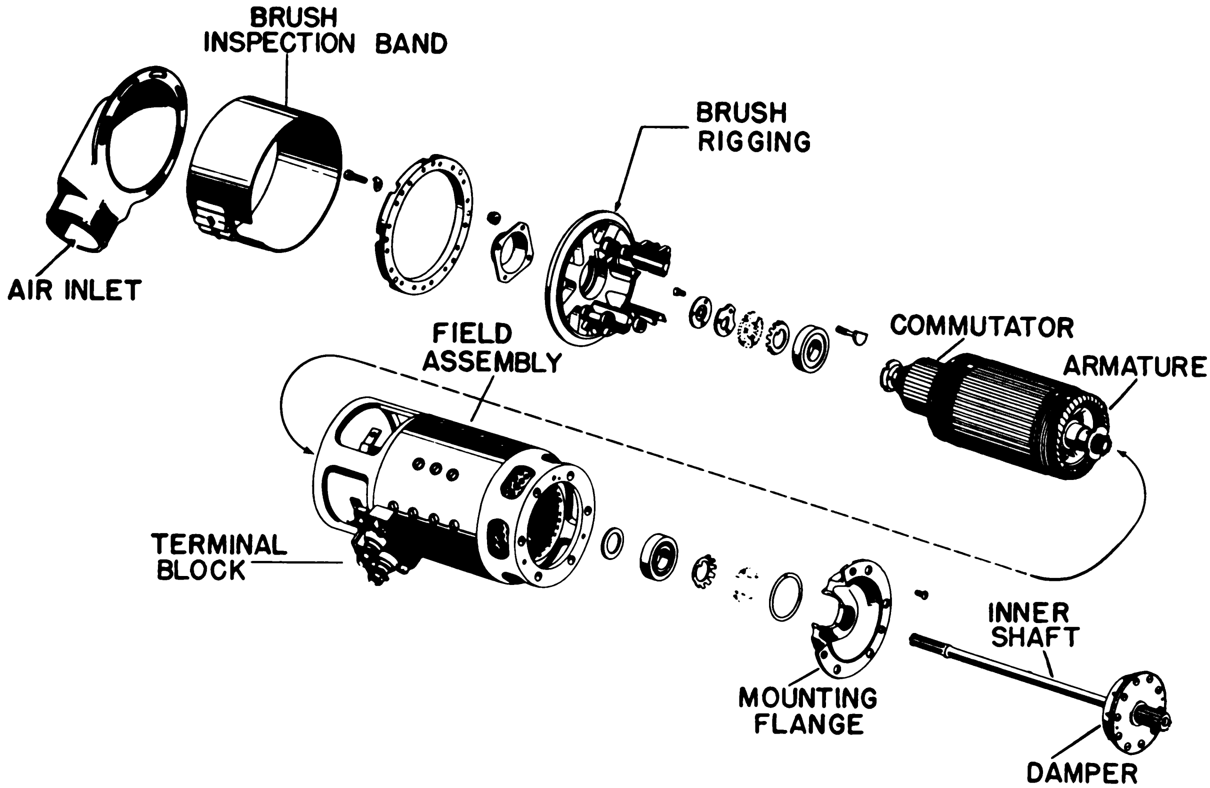


Figure 7-3.—Exploded view of an aircraft generator.

The brush rigging assembly consists of the brush holder yoke and bearing support, four brush holders, springs, terminal screws, and brush assemblies. A brush inspection band encloses the commutator end of the field frame and protects the brush rigging assembly. An opening in the air inlet cover at the commutator end of the generator provides a connection for the ventilating air tube.

The drive-end bearing support is fastened to the mounting flange and supports the drive-end bearing. The commutator-end bearing is supported in the bearing housing which is a part of the brush rigging assembly.

The internal electrical connections are brought to the terminal block. These connections are shown schematically in figure 7-2. They are as follows: a positive armature terminal B, a positive shunt-field terminal A, a negative armature terminal E, and an equalizer terminal D. The terminal studs provide connections to the aircraft electrical system.

INSPECTION

A preflight service inspection check consists of observing the voltmeter and ammeter on the instrument panel for proper generator operation.

Periodic inspection of generators includes the following:

1. Check for defects in the mounting flange. If defects are found, remove and replace generator. Also inspect mounting studs and nuts and safety wiring for security.

2. Check removable units such as ventilation tube, airblast cover, brush inspection band, terminal box, end shield, and conduit for tightness and general mechanical condition. Minor dents can be repaired. Parts with cracks must be replaced.

3. Check the generator and cable connections for signs of overheating. This is usually shown by discoloration of the parts affected or by an odor of burning. Clean or replace the metal parts. Repair any weak points in the insulation or replace the cable.

4. Check the commutator and brushes of the generator according to the directions that follow, under the heading ''Maintenance.'' If this inspection reveals defects which cannot be corrected while the generator is installed, it must be removed for shop repair or overhaul.

5. Provided there are no defects requiring removal of the generator, blow out the commutator end of the generator, and clean and blow out the terminal box if one is used. Tighten loose nuts and screws, and replace safety wires or cotter pins.

MAINTENANCE

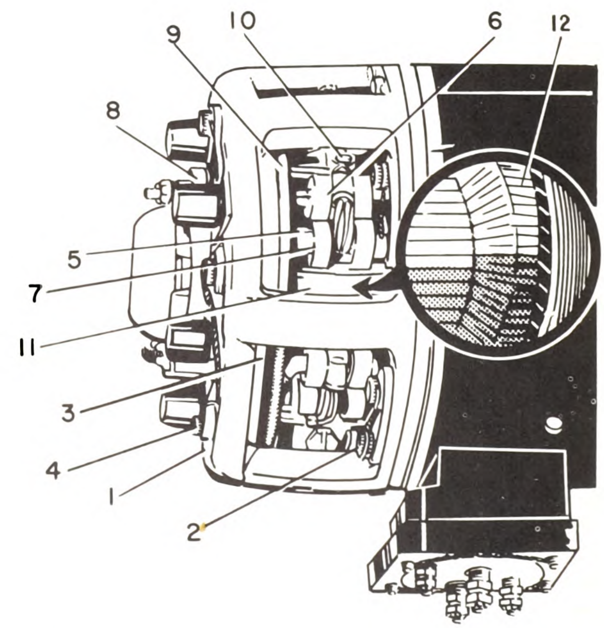
Generator failures or apparent failures are due to a variety of causes. Before removing a generator that is not delivering its rated voltage or current, determine that the trouble is not caused by a fault in the control, feeder, or regulating circuits or units.

Commutator and Brushes

The connection of the armature conductors to the individual commutator segments is made at the part of the segment referred to as the riser. This connection is secured in aircraft generators by use of hard solder or silver solder. Insulation of all segments from each other and from the armature shaft and core is accomplished by thin sections of mica between each segment and between the segments and the clamps which hold the segments to the shaft. The mica between the segments is cut to the same shape as the segments. That part of the mica directly under the brush is cut below the surface of the commutator bars.

When shop checking a generator, check to see that the commutator (fig. 7-4) has a smooth, worn surface around the entire circumference throughout the area spanned by the brushes. It should have an even brown or chocolate color. Any dirt, oil, or grease on the commutator must be removed. Check for brush sparking as evidenced by rough and pitted commutator bars. Look for loose connections to the commutator risers. This may be indicated by specks of solder on the surrounding field coils and connections.

Should the commutator be dirty, it must be cleaned. Oil and dirt tend to glaze the surface with a high-resistance coating. Remove the brushes; blow loose dirt out with air, being careful not to blow it into the housing. Wipe oil and grease out with a lintless cloth moistened with the appropriate cleaning solution; presently this is dry cleaning solvent P-S-661B. A high-resistance coating may be removed with No. 0000 or finer sandpaper (not emery cloth) folded over a flat, thin stick to hold the sandpaper in perfect contact with the commutator. Rotate the shaft slowly, moving the stick sideways to reach the whole width of the commutator bars. Do not hold the sandpaper in one position, as this will groove the commutator. Use light, even pressure. Blow out the dust with dry, clean compressed air and wipe off with a lintless rag dampened with cleaning solvent.



1. End shield.
2. End shield screw.
3. Brush holder yoke and bearing support.
4. Brush rigging screw.
5. Brush holder.
6. Brush spring.
7. Brush.
8. Outside cross connector.
9. Inside cross connector.
10. Brush terminal screw.
11. Commutator.
12. Riser.

Figure 7-4.—Generator brush rigging and commutator.

There are various methods of cleaning commutators, and another much used method utilizes a commutator stone. An advantage of this method is that the generator may be mounted on the aircraft or on the test stand in the shop.

The amount of runout or out-of-round of the commutator must be checked with a precision dial indicator and must be within the limits specified by the manufacturer or by the Bureau of Naval Weapons. If the commutator is found to have too much runout, it must be refinished. This may be done by turning the armature in a lathe. After turning, the mica between the segments should be undercut below the brush surface of the segments. Generally, this refinishing is performed by skilled machinists in well-equipped shops. Commutator cutting by a class B or C maintenance activity is authorized only as an emergency measure, provided that adequate personnel and equipment are available.

As the surface of the commutator gradually wears, the mica will eventually become flush with the brush surface of the segments. If this condition is not corrected by undercutting the mica, rapid brush wear is apt to result. Extreme care must be taken when undercutting to prevent the cutting tool from leaving the slot and scoring the brush surface of the commutator; also, great care must be exercised to avoid sharp edges on the commutator bars.

The following checks should be made when checking the generator brushes and brush rigging. Look for cracks in the brush holder yoke and check for tightness. Check for loose screws and defective safety wires. Check for loose brush holders and for dirt, grease, and oil. Check for security of jumper leaks between holders of like polarity. Check to see that no brush holder is bent out of alinement. Check for broken brush springs. Check the freedom of the brush in the brush holder. The brush should not bind or drag in the holder, but neither should there be enough clearance that a sloppy fit is obtained. Check all brushes for security of pigtail to brush and to terminal, and see that the wire is not worn or frayed.

The spring pressure applied to each brush by the brush spring must be within the range established by the manufacturer for that particular generator. If the spring tension is too strong or weak, the brush spring must be replaced. The tension is measured with a small spring scale and seldom exceeds 2 pounds per square inch of brush surface even on very large generators.

Check the brushes to see that they are not cracked or chipped. Check for pits due to sparking. Check for oil-soaked brushes. If the brush is oil soaked, it must be replaced. The oil acts as an insulator and terminal voltage will be lowered.

When checking the original brushes make certain that they are replaced in their original holders; otherwise, it may be necessary to refit the brushes. When brushes are placed in their holders, the brush springs should be carefully lowered until they make contact with the brush. Never release the brush spring unless it is in contact with the brush since this will allow the spring to strike the brush sharply, causing possible damage to the brush. Check for brush wear by measuring the length of the brush. It must be within the limits specified by the manufacturer.

When it becomes necessary to install new brushes, the following procedure is recommended. Pull the brush springs back only as far as necessary to allow removal of the old brushes; this may be easily accomplished by using a hook made of stiff wire. Attach the brush pigtails of the new brushes to the proper connections and secure the pigtails electrically. Insert the brushes in the brush holders. After the new brushes have been installed, steps must be taken to remove the old commutator film, fit the new brushes, and establish a new film. There are two methods of driving the generator when performing this operation: use a generator test stand or drive the generator as a motor.

The procedure to be followed when using a generator test stand follows. (NOTE: The procedures for using the generator as a motor are simitar and are discussed later in this chapter.)

1. Mount the generator on a test stand and make the proper connections.

2. Drive the generator at its lowest normal operating speed in the direction of normal rotation.

3. Using a commutator stone, such as an American Emery Wheel Grade 220 JE or equivalent, pass the stone lightly across the commutator four or five times. Do not allow the stone to stop while crossing the commutator, as this will result in a deep groove in the commutator surface. Stop the generator and remove the brushes for inspection of fit. The fit should be as shown in figure 7-5 (C). If not, repeat the procedure as above until a fit at least equivalent to (D) and (E) is obtained. A fit of 100 percent (C) is, of course, more desirable than the 70 percent as shown in (D) and (E).

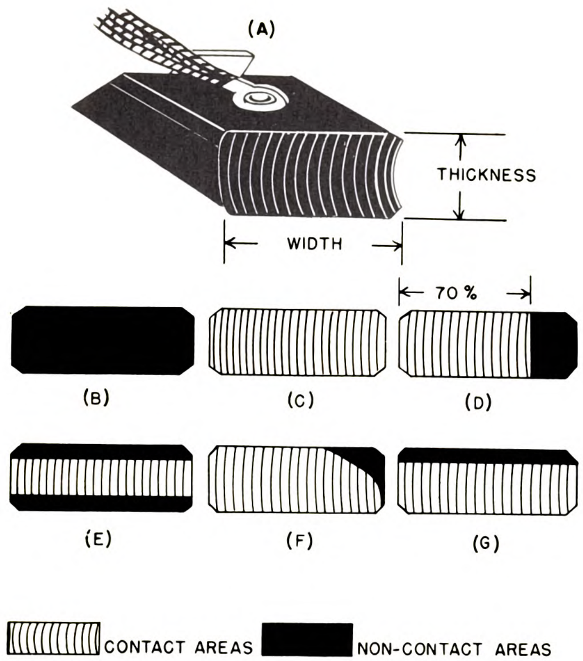


Figure 7-5.—Correct and incorrect brush fit.

4. When brushes have been properly fitted, blow out all carbon dust. Attach covers, cooling cap, and airhose.

5. Drive the generator at a speed midway between its normal speed range with proper airblast through it for cooling. Load the generator to its rated capacity. Total time with the generator running under load should be 2 hours. After approximately 30 minutes of running, shut the generator down and inspect the brushes for proper fit. In many instances additional stoning may be necessary.

6. After the last stoning and following a 2-hour run, the film on the commutator may be transparent. The brushes should take on a high gloss with the exception of a few possible scratches across the wearing surface of the brush caused by the grit of the stone.

TESTING

Armature

A common failure of armatures is the breakdown of insulation between the windings and the iron rotor, usually caused by overheating. Inspection of the commutator of such an armature will show a badly pitted or burned section. The burned area corresponds to the point at which the grounded coil is connected to the commutator bars.

An insulation resistance test of armatures may be made by use of a megger. Connect one lead of the megger to the shaft or core of the armature and the other lead to the riser of one of the segments. When the crank of the megger is turned, the condition of the insulation of the commutator and armature conductors will be indicated by the position of the pointer on the megger's dial. A reading of 10 megohms or better indicates good insulation.

Another reliable test for checking for armature grounds is to use a supply source of 110 or 220 volts, and a lamp connected in series with the source voltage. This test places a high voltage between the aramture winding and the core. The applied voltage breaks down any weak point in the insulation and current flows in the circuit. As a result of the completed circuit, the lamp glows. The test prod should be connected to a riser and not to the commutator bar as an arc or spark may burn and roughen the commutator.

A disadvantage of this test is that a comparatively strong current must flow through the filament of the lamp before it will glow. The amount of current required to give an indication depends upon the rating of the lamp used for the test. High-resistance grounds, therefore, will not be indicated by this test.

The disadvantage is overcome by connecting an ammeter in series with the lamp as shown in figure 7-6. The ammeter should be capable of measuring the maximum current to the lamp. With this arrangement, the ammeter registers even though the current is not strong enough to illuminate the lamp. The lamp, however, safeguards the ammeter by limiting the maximum current flow in the circuit. In this way, indications are obtained for short circuits over a wide range of resistance values.

The quickest and most convenient method in checking armatures for shorts is to use a growler, which consists of a coil wound around a laminated core (fig. 7-7). The shoes are shaped to fit the curvature of the armature. The growler is energized by alternating current, usually 110-volts, 60 cycles. A relatively loud hum results, which gives the growler its name.

When the armature is placed in the growler, its completes the magnetic circuit; its windings

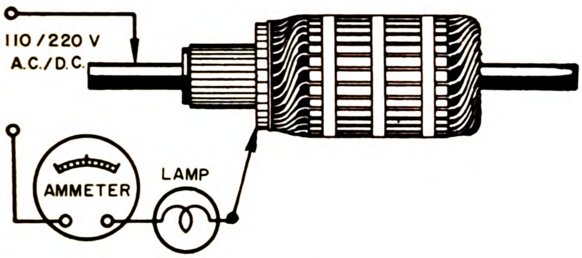


Figure 7-6.—Test procedure using lamp and ammeter.

act as the secondary of a transformer, with the growler coil forming the primary.

Shorts are checked by exploring the armature core with a thin strip of iron or steel such as a hacksaw blade. If the associated coil is normal, there will be no attraction for the hacksaw blade. Where a short circuit exists, the hacksaw blade will flutter. By rotating the armature, each segment and therefore each coil can be tested. Smoke rising from the armature immediately indicates faulty insulation.

A growler may be used for checking armatures for open circuits. In this test a meter and test prods are needed; these are usually a part of the growler assembly. (See fig. 7-7.) The testing procedure is as follows: With the growler energized, and the armature in the growler, the two test prods which are connected to the ammeter are held against the risers of two adjacent commutator bars. The armature and test prods are rotated together until a maximum metal deflection is obtained. This position of

Figure 7-7.—Growler used for checking armature.

the test prods, relative to the growler, is maintained while the armature is rotated. The same meter reading will be given for all armature coils that are good. An open coil is indicated by a zero reading. A lower reading on one pair of risers, relative to the others obtained, indicates a shorted coil.

Another method of checking armatures for open circuits is through the use of a battery and voltmeter. The armature is energized as shown in figure 7-8 (A), and the voltage is measured between each pair of adjacent commutator bar risers. An open is indicated by a maximum voltage reading.

If coil B (fig. 7-8 (B)) is open, the voltmeter connected as shown will read the full applied voltage. The voltage between commutator bars 1 and 2, and between 3 and 4, will be zero since no current would flow with coil B open.

If coil B were not open, current would flow through all coils, but the voltage drop across each would usually be too low to indicate on the voltmeter. Because maximum voltage occurs across an open-circuited coil, the meter must have a range at least equal to the voltage applied. The current limiting resistor prevents undue heating of the armature coils.

In figure 7-8 (B) a lap wound armature is shown, as this type of winding lends itself better to illustration of the method of testing. Wave windings are arranged differently, but the above method of checking for opens also applies.

An aid in reducing the armature current is to energize the armature at two points, so that two parallel paths of equal resistances are established through the armature as shown in figure 7-8 (A). For aircraft generator armatures, which are wave wound, this condition can be met by applying the energizing current at two points 90 mechanical degrees apart for a 4-pole machine, and 60 degrees apart for a 6-pole machine.

Field Testing

When testing the field of a generator, before applying the test, trace the field circuit in order to determine whether or not the field is grounded intentionally at one point. If this is the case, remove the ground.

Grounds may be checked with a 110-v. or 220-v. test lamp continuity checker connected between a field-coil terminal and the frame of the machine. This is similar to the armature test shown in figure 7-6.

Open and short circuits may be checked with an accurate ohmmeter (fig. 7-9). If the resistance reading is below normal, a short circuit exists. An open coil is indicated by a near infinity reading. The shunt-field resistances of commonly used aircraft generators are about two to three ohms.

If data are not available as to the normal field resistance, the resistance of the field in question can be compared with that of an identical generator known to be in good condition. An ordinary continuity tester is satisfactory for checking for open circuits only.

Another method of checking the field coils is with a voltmeter and battery. (See fig. 7-10.) The voltage drop across each field coil should be the same. A higher voltage drop reading

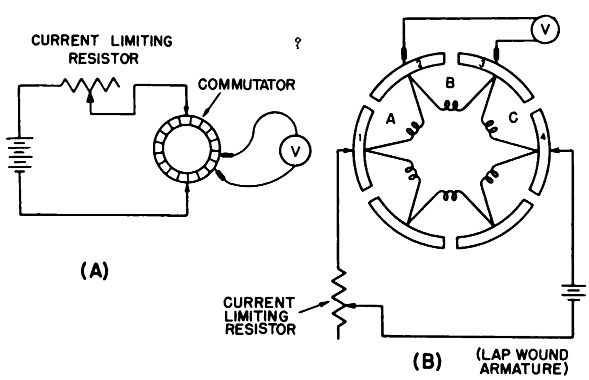


Figure 7-8.—Checking armature for opens with battery and voltmeter.

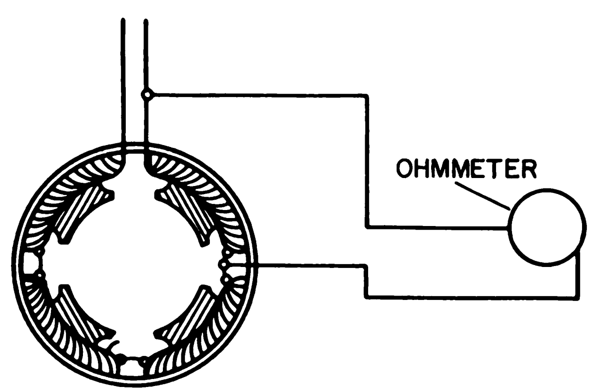


Figure 7-9.—Testing field winding by ohmmeter method.

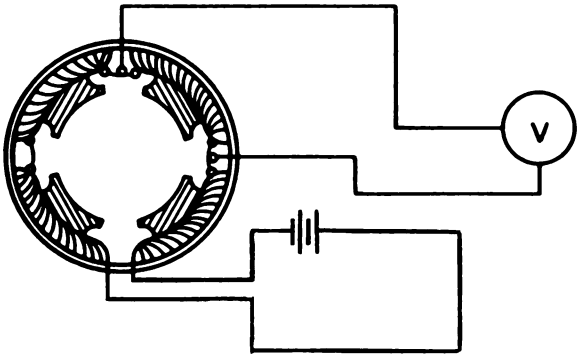


Figure 7-10.—Testing field winding using a voltmeter and battery.

(full battery voltage) indicates an open circuit; a lower voltage drop indicates a short.

An ammeter and battery can also be used to check for opens and shorts. The battery, ammeter, and field coils are connected as shown in figure 7-11. The correct current can be calculated by Ohm's law if the resistance is known, or the current can be compared with that of an identical generator known to be in good condition.

The field poles in an aircraft generator are lightly constructed. Consequently, they often lose their residual magnetism. Without residual magnetism, a self-excited generator connot build up voltage when rotated. Residual magnetism may be restored by several methods. The method used is determined by the existing conditions and time available. The procedure

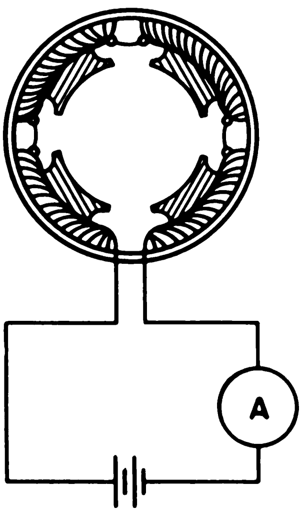


Figure 7-11.—Testing field winding using an ammeter and battery.

in all cases includes sending a current of proper direction and magnitude through the field windings. This operation is called flashing the field.

''Motoring'' (running a generator as a motor) is accomplished by connecting it to a battery in somewhat the same manner as it would be connected to operate as a generator. If a generator ''motors,'' it is a fair indication that it will operate as a generator. This test should be resorted to only when a generator test stand is not available. Motoring a generator also automatically flashes the field.

As previously mentioned, running a generator as a motor is a means of obtaining generator rotation when seating brushes.

Refer to figure 7-12, which is a pictorial and schematic drawing of a typical aircraft generator that is arranged to run as a motor. The procedure for motoring the generator is as follows.

Secure the generator in a padded V-block or vise, remove the airblast and terminal-box covers, and make certain all nuts and screws are tight and secured by safety wires or cotter pins.

Turn the rheostat to cut out all resistance, and close the switch. With the switch closed, the generator should start and run as a motor. If the generator tends to overspeed, open the switch at once, and check for loose connections in the shunt-field circuit.

Close the switch and run the generator as a motor long enough to get a steady current reading.

Each type of generator will draw a specific number of amperes when running as a motor. To determine the number of amperes that a generator should draw when running as a motor, use the following procedure. Take a generator of the same type that is known to be good, run it as a motor at a fixed speed (approximately 4,000 rpm) or rheostat setting, and observe the current drawn. Use the amount of current drawn by the generator that is known to be good as a check.

If the generator being tested draws an excessive current, it is an indication of electrical or mechanical trouble.

If the generator being tested runs as a motor and draws the proper amperage, it is reasonably certain that the generator will operate properly when installed on an engine.

The generators installed on current aircraft do not require lubrication between major overhaul periods. The ball bearings are lubricated

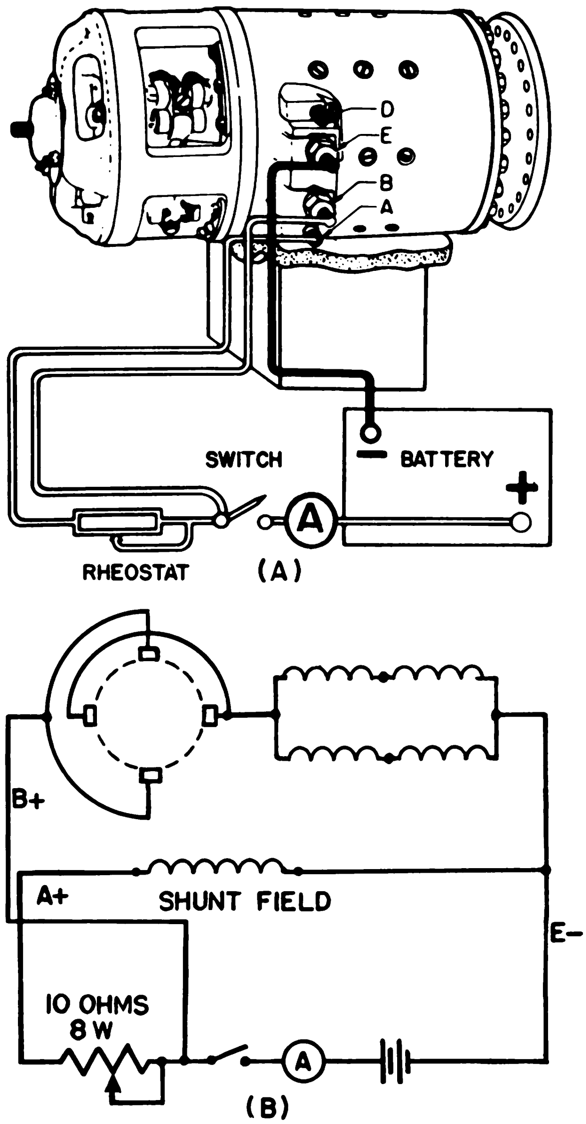


Figure 7-12.—Running a generator as a motor.

by the manufacturer. Upon major overhaul, a small amount of grease should be added to the bearing cavity. Under normal circumstances, bearings in good condition, properly installed, are satisfactory for over 1,000 hours of operation.

OPERATIONAL CHECK

A generator test stand is designed to subject the generator, voltage regulator, and reverse-current relay to as many of the aircraft operating conditions as possible.

A test stand must have adequate speed to drive a generator in excess of its maximum rated rpm to provide an "overspeed check." It must also have ample driving power to provide an overload test of the generator. A suitable test stand must also have an easy speed change mechanism and maximum power within all speed ranges.

The test stand must provide adequate cooling for the generator. A separate blower is usually installed for this purpose. A gate valve is employed in the air line to control the pressure. Some generators, although having a built-in fan, also require blast cooling.

A test panel or load box is required with the generator drive unit. A d-c test panel is made up of a blank of resistors (for loading the generator), a voltmeter, and an ammeter with suitable ranges and shunts. A main line switch is incorporated so that all the load may be removed with one switch. Large carbon pile rheostats can be used as a load, but the adjustment tends to "creep" and requires constant attention.

Control of generator voltage can be achieved with a manually operated field rheostat, but it is standard practice to use a dependable voltage regulator.

Many test stands are driven by constant speed a-c drive motors using split-pulley variable-speed changers. These motors should always be started and stopped at low drive-head rpm with no load on the generator. Heavy currents flow in drive motors whenever they are started with a heavy load, or when they are overloaded or stalled. Such currents result in blown fuses, open circuit breakers, and burned-out motors.

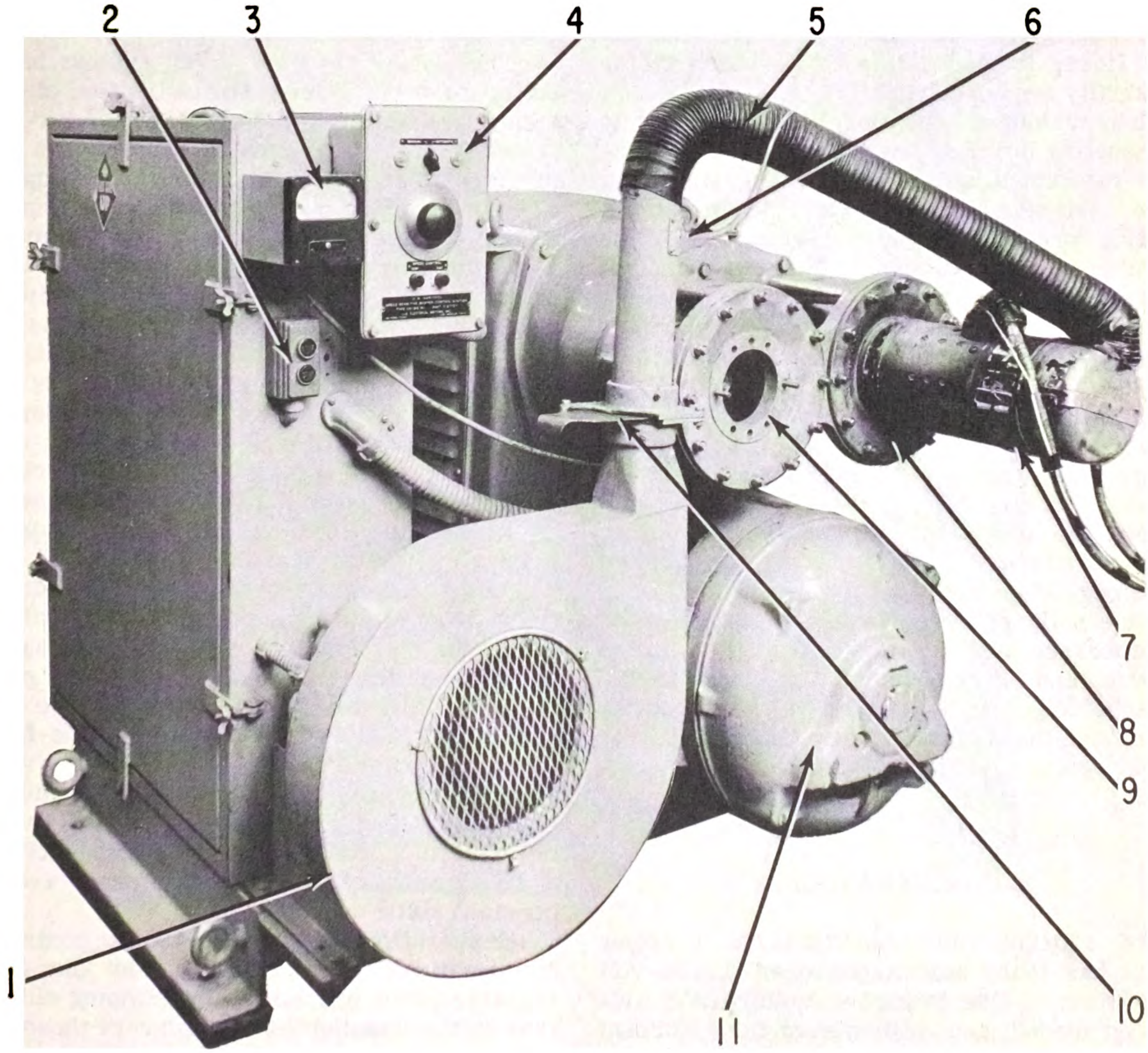
Under emergency conditions, a test panel may be improvised. Landing lights, motor alternators, or motors requiring considerable current can be used. Resistors make the best load. They can be wound on ceramic tubes or they may be made self-supporting. It is important to avoid exceeding the ampere rating of the resistance wire. Ordinary aircraft ammeters, voltmeters, and switches can be mounted conveniently on a panel.

Figure 7-13 shows a typical generator test stand. This stand is used with the test assembly shown in figure 7-14. The test stand provides variable speed power for driving the aircraft generator under test. The test assembly, a component part of the test stand, provides the facilities for loading, testing, and measuring the output of the following aircraft power equipments:

a-c generators, d-c generators, regulators, reverse-current cutouts, and inverters. Since the test stand assembly can be adapted to test motors, relays, and switches, the combination of test stand and test assembly provides a complete system for the functional testing of most aircraft power equipment.

The type MA-1 aircraft generator test stand (fig. 7-13) provides for the rapid and accurate testing of both direct-current and alternating-current aircraft generators.

The aircraft generator test stand simulates operational service conditions for the testing of generators. The varidrive unit provides a means of regulating generator speed from



1. Blower fan housing.
2. Start-stop push buttons.
3. Tachometer indicator.
4. Speed sensitive master control station.
5. Flexible airhose.
6. Pitot tube.
7. Test generator.
8. Generator mounting bracket, 60-cycle input.
9. Generator mounting bracket, 50-cycle input.
10. Blast gate.
11. Varidrive motor.

Figure 7-13.—Aircraft generator test stand, type MA-1.

3,000 to 9,000 rpm within 3 percent no-load to full-load regulation at the output shaft.

The test assembly (fig. 7-14) is a load bank for testing aircraft power equipment under actual load conditions. The front panel contains the terminals, switches, and meters necessary for the complete test. It is possible to measure field current, load current, generated voltage, and dissipated power for every input. All the meters have their terminals located on the front panel and are connected into the test assembly circuits by means of meter links. By removing these links, it is possible to use each meter individually for benchwork.

When making a test, mount the generator on the mounting bracket located at the right (looking at the mounting bracket) for 60-cycle input to the test stand drive motor, and on the left mounting bracket for 50-cycle input. If the generator is of the 10-inch bolt circle diameter, mount it directly on the generator mounting bracket, slipping its shaft into the spline adapter and then into the spline coupling and tightening it to the bracket with the nuts provided. For a 5-inch bolt circle diameter, use a mounting adapter plate. Connect the flexible airhose (5, fig. 7-13) between the outlet of the blower duct and the air inlet on the generator cover. Connect the pitot tube (6) to the manometer (pressure gage). The quantity of air supplied can be regulated by the blast gate (10).

Conduct the operational test of the generator in accordance with the directions given in the Operation and Service Instruction Manual for the test assembly that is being used. When testing a generator the Overhaul Instruction Manual for the particular generator should also be consulted.

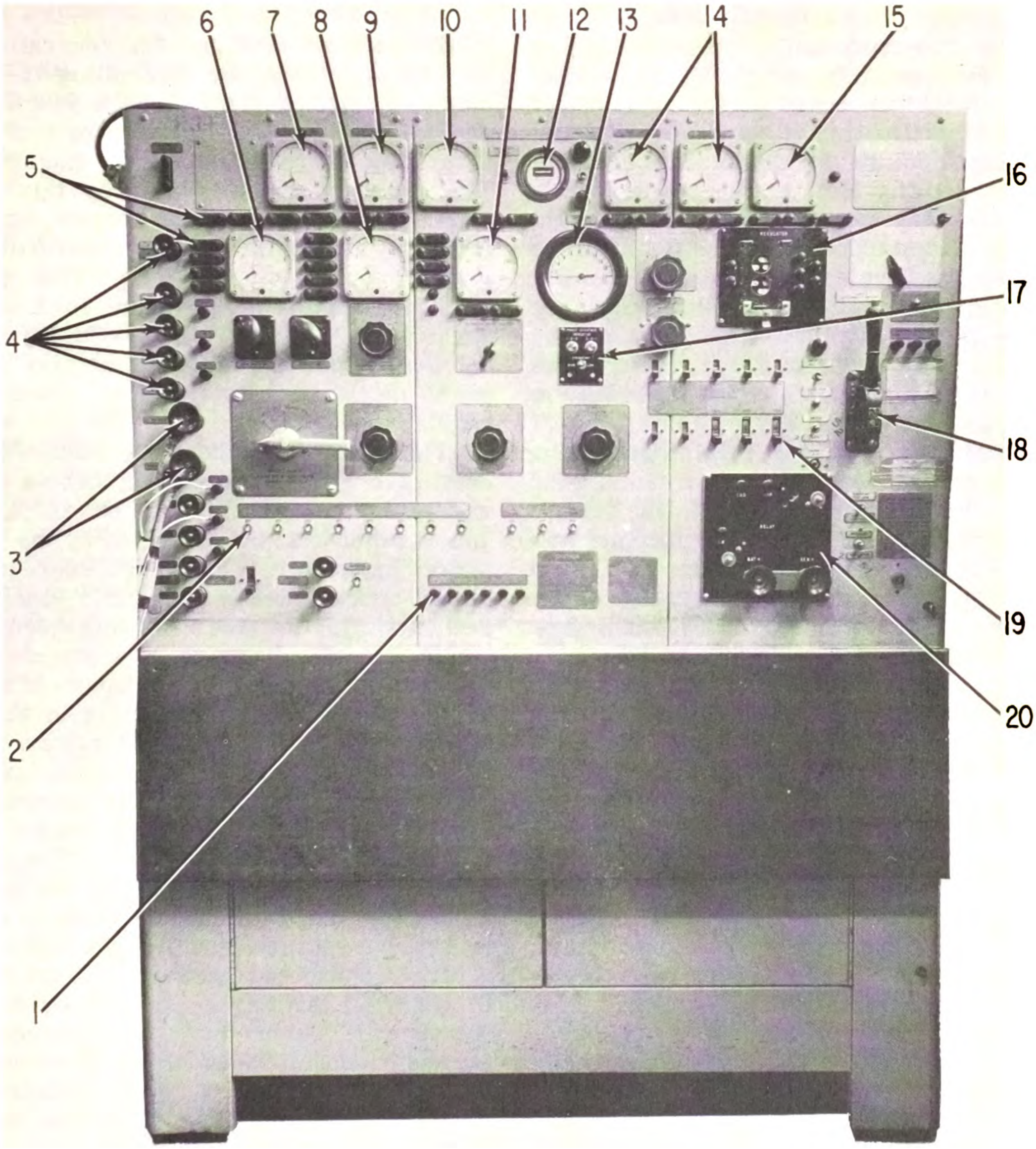
A-C GENERATORS

The 120/208-volt, 400-cycle, a-c power system has many advantages over the 28-volt d-c system. Due to higher voltage and a 4-wire (grounded neutral) system, the current carried in each wire is only a fraction of that required for the same power in a 28-volt d-c system. This permits the use of much smaller aircraft wiring with a great saving in weight. The a-c generator itself, especially in the larger sizes, as well as many of the system control and protection components, is lighter. While 12 kilowatts appear to be the practical limit to the size of a d-c generator that can be successfully mounted on an aircraft engine, 60 kilovolt-ampere a-c generators are being tested and even larger sizes seem practical. Service difficulties, such as high altitude commutation problems and brush wear, are greatly reduced in a-c generators. Some types of a-c generators now under development completely eliminate brushes. The single-phase a-c generator, used extensively in the past and not as advantageous as the 3-phase a-c generator, has advantages over the d-c generator and is still used to some extent today.

The use of the a-c power system has resulted in better design and utilization of equipment. A typical piece of electronic gear, powered from d-c power, may have a small inverter as an integral component for supplying a-c power and a small dynamotor for supplying higher voltage d-c power. These components are very heavy for their relative power outputs as well as being sources of unreliability and increased maintenance. A comparable piece of a-c powered electronic gear could obtain various a-c voltages and small amounts of d-c power by the use of simple transformers and transformer-rectifiers, respectively. These components are light-weight, simple, reliable devices. For the past several years, nearly all of the new aircraft designs have included a-c primary power systems.

As total aircraft power requirements continue to grow, and as the majority of aircraft equipment is "swung over" to a-c power, it can be seen that the predominant power system for naval aircraft of the future will be the 3-phase, 120/208-volt, a-c system. The factors which determine the frequency of the voltage produced by a generator are the number of magnetic poles in the machine and the rate of rotor rotation. With the number of poles a fixed quantity, constant frequency requires constant rotor speed.

Early attempts were made to control the frequency of a-c generators by the use of variable-pitch propellers or slipping clutches. Due to the unsuitability of either of these early methods, most a-c generator power was of variable frequency; that is, it was generated by an a-c generator directly driven by the main reciprocating engine. This usually gave approximately a 2 to 1 speed range from maximum engine power to minimum cruise, and the engine gear ratio was chosen to give power from 400 to 800 cycles per second. However, ground idle speed of the engine was usually considerably



1. A-c voltage regulator terminal.
2. A-c generator load switches.
3. D-c generator input.
4. A-c generator input.
5. Meter link terminals.
6. Single-phase wattmeter.
7. Single-phase ammeter.
8. Three-phase wattmeter.
9. Three-phase ammeter.
10. High-low frequency meter.
11. A-c voltmeter.
12. Frequency meter.
13. Pressure gage.
14. D-c ammeters.
15. D-c voltmeter.
16. Voltage-regulator pad.
17. Phase sequence indicator.
18. Load disconnect switch.
19. D-c generator load switches.
20. Relay pad.

Figure 7-14.—Aircraft electric power equipment test assembly, model 7085.

below that required to obtain 400 cycles, and no usable power could be taken from these generators on the ground.

It soon became apparent that great weight savings and vastly improved performance would be effected in utilization of equipment if power could be supplied at an essentially constant frequency. As the total power requirements grew, the point was soon reached, from a weight and performance standpoint, where it was more advantageous to furnish the a-c power at a constant frequency. The constant frequency is obtained in these aircraft either by a hydromechanical constant-speed drive, which converts the variable main engine speed to a constant-speed output to drive the generator, or by use of an air or gas turbine generator drive. The air or gas turbine may obtain its air supply by using bleed air from the jet engine compressor or from a separate compressor. The hydromechanical drive will hold the frequency steady within a few cycles of the desired 400, and load and fault transients are held approximately within a 380- to 420-cycle range. Air or gas turbine drives are somewhat smoother in operation and hold steady state frequencies within ±10 cycles.

The principle of control is: part of the generator's a-c output is fed to a frequency-sensitive control device which senses any drop or rise in frequency corresponding to a drop or rise in generator rotor speed. This device then varies a control voltage fed to the control mechanism of the constant-speed drive, which, in turn, varies the speed at which the rotor is being driven and brings the speed back to that necessary to produce the desired frequency.

Although constant rotor speed insures a constant frequency, it does not insure constant voltage at the output terminals of a generator supplying power to a varying load. In accordance with Ohm's law, the voltage drop within the armature windings will vary as the product of the load current and the resistance of the armature winding. Because the voltage drop across the armature resistance must be subtracted from the total voltage generated, the armature resistance is held to a minimum. Since the output voltage will vary with any change in load current or armature resistance, the total generated voltage must be made to vary along with any features which tend to change either of these two items—such as a change in external load—if the output terminal voltage is to remain constant.

EXCITATION

Effective control of the generated voltage can be maintained by controlling the strength of the magnetic field through which the conductors are moving. The strength of the magnetic field is regulated by a voltage regulator. The current which generates this magnetic field, called the exciting current, is supplied either by an auxiliary d-c generator (called the exciter) or by a rectifier. This exciter is usually mounted on the same shaft as the a-c generator. When a rectifier is used, it changes the a-c output of the a-c generator into d.c., which is fed back to the field, via the voltage regulator.

The present military specification for aircraft a-c generators states that no source of excitation or preenergization should be required other than that supplied by the generator and/or regulator. To meet this requirement, direct-connected d-c generator exciter units are integrated into the a-c generators.

The chief advantage of a direct-connected exciter, aside from the advantage of being able to use small regulators acting in the field of the exciter, is that each generator has its own independent source of excitation, and no dependence is placed upon any external source of electric power. In a multigenerator installation, failure of the excitation source for one machine does not render the complete system inoperative as would be the case in a common external excitation system. Furthermore, with a direct-connected exciter, it is not necessary to transmit excitation power any distance in the aircraft, thus reducing the chances of losing excitation due to open or short-circuited wiring. To make the exciter an integral part of the machine, it is mounted on the same shaft as the a-c generator field poles and sliprings.

In contrast to d-c generators, the magnetic field coils in most aircraft a-c generators are rotated, and stationary windings pick up the induced alternating currents. By making the higher voltage output windings stationary, and by rotating the lower voltage magnetic field, the characteristic sparking at higher voltages at the brushes is reduced.

SINGLE-PHASE A-C GENERATOR

The single-phase type a-c generator is finding less application in aircraft that demand large amounts of a-c power. However,

it is widely used in aircraft such as trainers and some fighters. Due to the smaller power demands of both the a-c and d-c systems of these aircraft, usually one generator is used to provide both alternating and direct current. These are known as a-c/d-c or double-voltage generators.

Inductor Type

Figure 7-15 shows the schematic of an inductor type single-phase a-c generator. In a-c generators of this type the armature coils are stationary in the magnetic field. The rotor has no coils, only projections. The rotation of these projections past the armature coils causes the magnetic flux (magnetic lines of force) enclosed by the armature coils to pulsate periodically. This generates in the armature coils a pulsating (a-c) voltage having a frequency proportional to the speed. As in the case of a d-c generator, the voltage depends on the saturation characteristics of the flux paths (iron and airgap), the field current, and the speed. Unlike a d-c generator, which can supply its own shunt-field current, the field current for an a-c generator must be supplied by some other source, either an exciter or the d-c section of an a-c/d-c generator.

As in the case of a d-c generator, the voltage of an inductor a-c generator increases with field current, but only up to a certain point. In an inductor a-c generator, excessive field current saturates the iron, reducing the magnitude of the flux pulsations and the voltage. That is, if the field current is increased beyond a certain point, the voltage will decrease instead of increase. The inductor a-c generator has inherently high reactance (inductive reactance), which means that an unusually large increase in field current would be required to maintain its voltage if a load were applied directly to its terminals. To provide

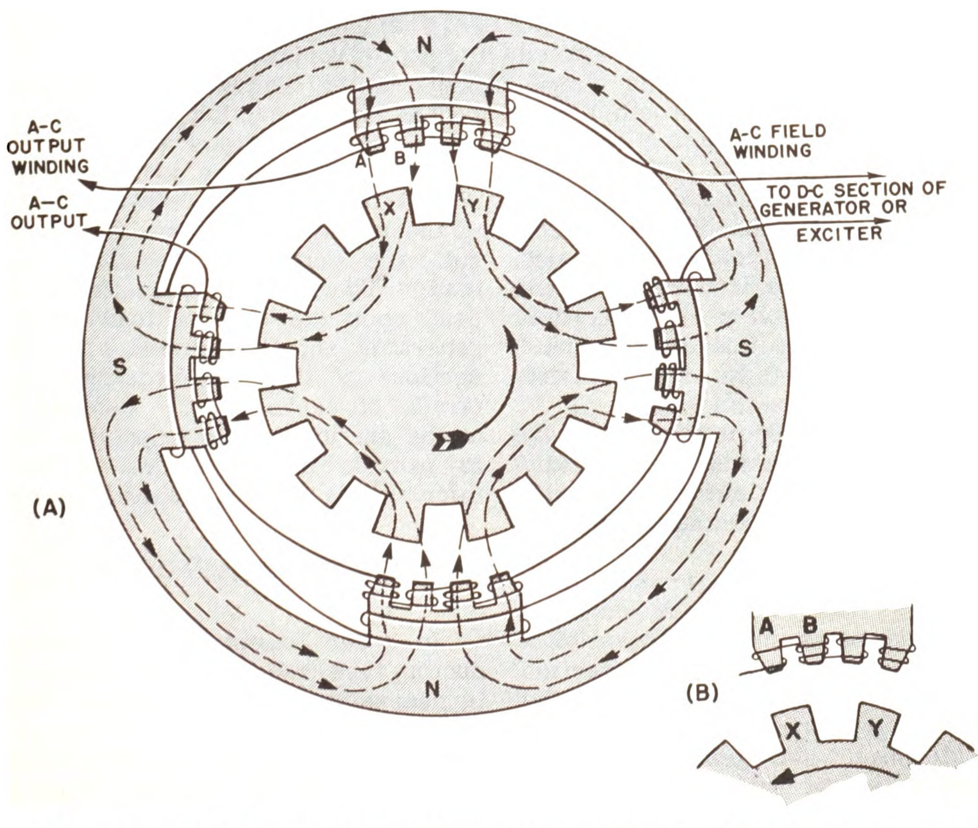


Figure 7-15.—Schematic drawings of a-c generator (exciter not shown).

for additional field current without danger of oversaturation would mean increased size and weight. Consequently, the positive reactance (inductive reactance) of the generator itself is partially compensated by the insertion of negative reactance (capacitive reactance) in the armature circuit in the form of a 10 to 15 microfarad capacitor.

The a-c generator shown in figure 7-15 has two windings in the stator: the a-c field winding, and the a-c output winding. The a-c field winding is connected across the d-c output. Rotation of the d-c armature thus produces a flow of direct current through the a-c field coils which produces a magnetic field in the magnetic circuit of the a-c stator. As the rotor turns, the reluctance of the magnetic circuit through the coil cores and rotor teeth varies, causing a variation in the flux. This change in the magnitude of the flux through the coil cores induces the voltage in each coil.

For example, as the rotor tooth X approaches coil A (fig. 7-15 (A)), the flux through coil core A will increase while that through coil core B will decrease. The voltage induced in coil A, therefore, is opposite to that induced in coil B. To make these voltages additive, the coils are connected as shown. As the rotor continues to rotate, tooth X will move away from coil A and tooth Y will approach coil B (fig. 7-15 (B)). This causes the flux to decrease through coil core A and increase through coil core B. This produces induced voltages opposite to those induced with the rotor in the position shown in figure 7-15 (A). Thus, an a-c voltage is induced in each coil. All coils are influenced simultaneously by the rotor teeth as described for coils A and B.

The a-c voltage is maintained constant by an a-c voltage regulator which automatically adjusts the alternator's field current with changes in generator speed and a-c load.

A-C/D-C Generator

Figure 7-16 shows a cutaway view of a typical a-c/d-c generator. The a-c section is a single-phase a-c generator; thus, the operation of this generator is similar to an ordinary single-phase a-c generator. The major difference is that instead of a small d-c generator (exciter) which would provide only the field current for the a-c generator section, the d-c section is capable of providing considerable d-c output. Thus, this type generator also provides d-c power for the aircraft's d-c loads.

The generator shown in figure 7-16 is similar to those described earlier insofar as mounting, driving, and cooling are concerned. The d-c section is a standard d-c generator, with rotating armature and commutator, stationary brushes, and stationary shunt, compensating, and commutating fields. It is designed to work along with the shunt field controlled by a voltage regulator. The d-c sections of two generators may be operated in parallel.

The a-c section is an inductor a-c generator, with a 12-projection rotor, stationary armature, and stationary field. It is designed to operate individually with an external capacitor in the armature circuit and with the field controlled by a voltage regulator. They cannot be operated in parallel.

It is a high-speed generator (4,400/8,000 rpm) with a d-c output of 6 kilowatts (30 volts at 200 amperes). The d-c shunt-field current is 8 amperes at full load.

The a-c section of the generator provides 1.2 kva of variable-frequency (800/1,600 cycles) power at 120 volts. The maximum field current of the a-c section is 3.3 amperes.

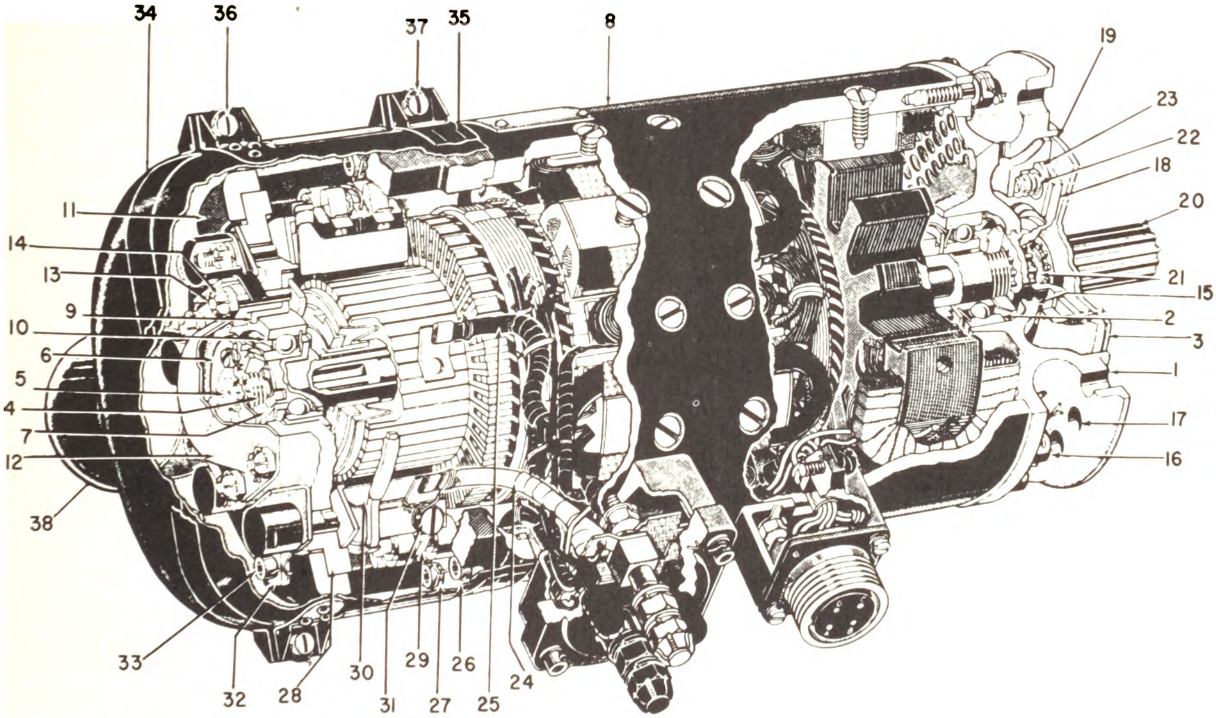
Figure 7-17 shows a schematic of a typical installation using an a-c/d-c generator. It should be noted that four of the five sections of the compensating capacitor in the a-c circuit are connected in series with the a-c load. The number of sections used will depend upon the type of load to which the a-c generator supplies power. The 4 connected sections of this capacitor provide 11 microfarads of capacitance. By proper selection of the sections of the capacitor it is possible to provide a capacitance of from 1 to 15 microfarads in 1-microfarad steps.

COMPENSATING CAPACITOR

In order to obtain rated output from inductor type a-c engine-driven generators, it is necessary to use a compensating capacitor in series with the output (a-c generator) windings. The purpose of this compensating capacitor is primarily to compensate for the internal reactance of the a-c generator. However, the load power factor also affects the amount of

compensation that should be provided, particularly at the higher frequencies. The compensating capacitor counteracts the inductive effect of both the a-c generator winding and the load, thereby improving the circuit power factor so as to produce maximum power in the circuit for a given voltage and current.

The amount of compensating capacitance required at a given speed (frequency) is determined primarily by the inductance of the



1. Mounting flange.
2. Drive-end bearing.
3. Vibration damper.
4. Outer shaft.
5. Inner shaft.
6. Retaining washer.
7. Beveled nut.
8. Field frame.
9. Brush rigging insert.
10. Commutator-end bearing.
11. End shield.
12. Oil seal cap.
13. Positioning screw.
14. Castle nut.
15. Grease seal.
16. Mounting flange screw.
17. Mounting hole.
18. Vibration damper disk, inner.
19. Vibration damper disk, outer.
20. Drive-end shaft extension.
21. Vibration damper washer.
22. Vibration damper spring.
23. Vibration damper plate.
24. Positive B lead.
25. Negative field lead.
26. Plate.
27. End shield screw.
28. Brush holder yoke and bearing support.
29. Brush terminal.
30. Brush holder.
31. Brush terminal screw.
32. Clamp.
33. Brush rigging screw.
34. Airblast cover.
35. Clamping ring.
36. Airblast cover screw.
37. Clamping ring screw.
38. Cooling air inlet.

Figure 7-16.—Cutaway view of a-c/d-c generator.

a-c generator windings. A common misconception is that the purpose of the compensating capacitor is to correct solely for the power factor of the load. This mistaken idea has been encouraged by the fact that a compensating capacitor was a part of some equipment.

An a-c engine-driven generator can supply about one-third of its rated current without a series compensating capacitor in the a-c generator circuit. Some aircraft installations having small a-c load do not include a compensating capacitor. However, when an additional a-c load is added to the system, it becomes impossible to adjust the voltage regulator so that the voltage is maintained constant at all loads and speeds. The only solution is to install a compensating capacitor.

The a-c voltage which the voltage regulator should attempt to maintain constant at 120 volts is the voltage on the load side of the compensating capacitor. Therefore the voltage regulator lead should be connected as shown in figure 7-17. Notice that the voltage regulator lead is

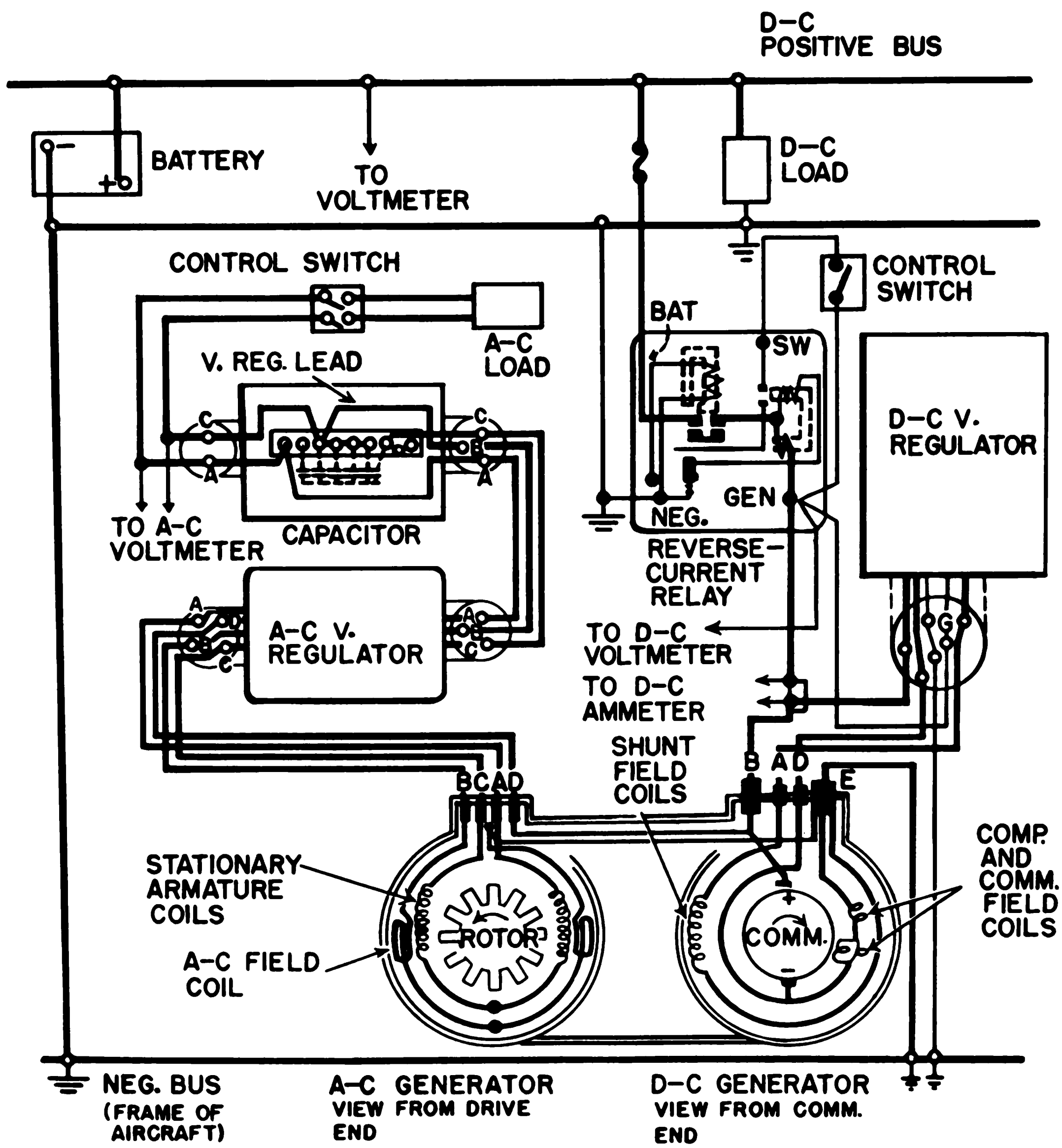


Figure 7-17.—Typical system connections, a-c/d-c generator.

connected to the load side of the compensating capacitor rather than to the line side.

THREE-PHASE A-C GENERATOR

Present military specifications require that the basic aircraft a-c power system voltage have a value of 120-208 volts. These voltages are obtained by designing the generator to produce 120 volts per winding and connecting the windings to form a wye system as shown in figure 7-18 (A). When so connected, the voltage between the neutral wire and any one of the phase wires or lines—that is, the line-to-neutral voltage—will be 120 volts. The line-to-line voltage in a wye-connected system equals 1.73 times the line-to-neutral voltage, and in this case is 1.73 times 120, or 208 volts. (NOTE: Refer to Basic Electricity, NavPers 10086-A for basic information on 3-phase circuits.)

By comparing the circuits ((A) and (B) of fig. 7-18) it can be determined that a distinct advantage of the wye over the delta system is that two voltages are available from a wye-connected system; however, the delta system is used for supplying power to certain aircraft instruments. The lower voltage of the wye system may be applied by connecting a load between a line and neutral, the higher voltage by connecting a load line-to-line across two phase coils.

When a load is connected line to neutral, the voltage generated by a single-phase winding in the generator will appear across it. Because this is the lower of the two voltages, the current will be correspondingly lower and will flow through the load and only that phase winding across which the load is connected.

When a load is connected line-to-line, two phase windings will be in series across it. The

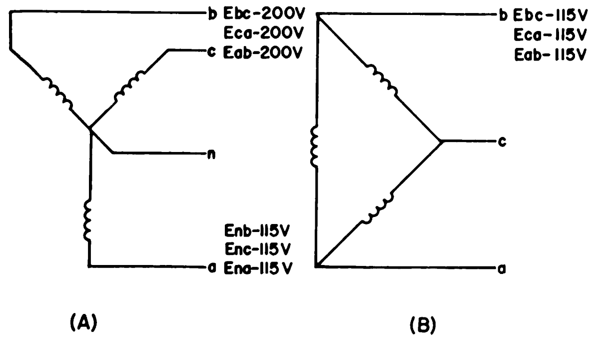


Figure 7-18.—Wye-delta voltage relationships.

vector sum of the two generated voltages will be applied and will equal 1.73 times the voltage of a single phase, as stated previously. Because the power is proportional to the product of current and voltage, the higher voltage will require less current for the delivery of an equal amount of power. With the higher of the two voltages and an equal current flow, power will increase by a factor of 1.73, the factor by which the voltage increased. Obtaining increased power by increasing voltage instead of current allows the use of smaller current-carrying conductors in both the distribution system and the generator; this makes the system lighter in weight, less costly, and more adaptable for supplying power to a wide variety of loads.

In the 4-wire grounded neutral system as applied to aircraft, the neutral wire is connected to the frame of the aircraft, which in this case constitutes ground. The 3-phase wires are then connected to 3-phase buses from which power is taken to supply the various loads. Those loads operated line to neutral are connected between one of the buses and the aircraft frame. Those operated line to line are connected between two of the buses.

The line-to-line voltage found in a 3-phase, wye-connected system is the vector sum of the voltages generated by two separate phase windings. Because a phase difference of 120 degrees exists between the two generated voltages, they will reach their peak amplitudes at different times and consequently must be added vectorially, not directly.

Figure 7-19 shows a typical 3-phase a-c generator. This a-c generator is an engine-driven, wide speed range, variable-frequency power supply. It provides 30-kilovolt-amperes (kva) of 3-phase power at 120/208 volts, 400/800 cycles at a 90 percent minimum lagging power factor, when rotated from 4,000 to 8,000 rpm.

It has an integral d-c exciter which provides the excitation for the rotating field. The exciter generates d-c power which is fed through its own shunt field as well as to the rotating field of the generator. Regulation of the a-c output voltage is accomplished by varying the external resistance in series with the exciter shunt field thereby controlling the exciter output and consequently the rotating field input which, in turn, determines the a-c output voltage.

Figure 7-20 is a disassembled view of the main assembly of an a-c generator. It shows those items which are of importance to operating personnel.

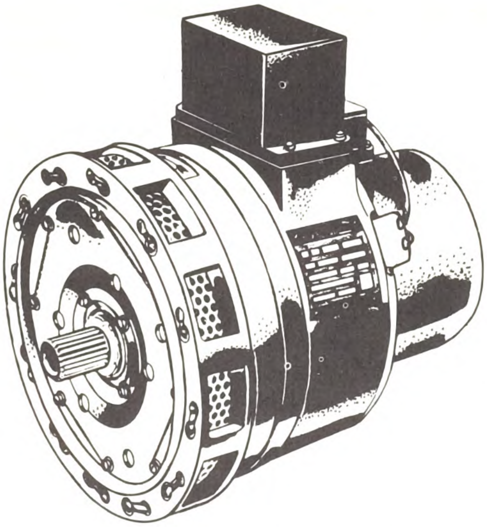


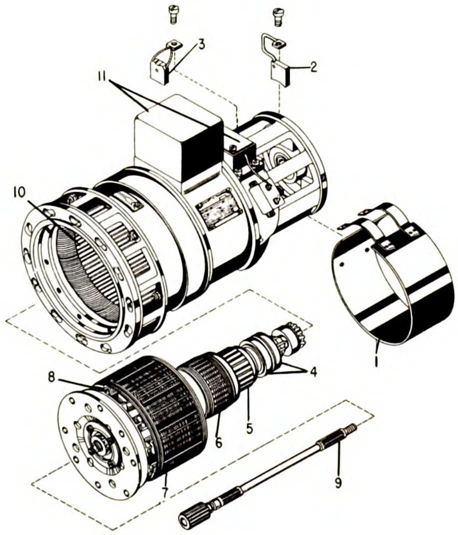
Figure 7-19.—Three-phase a-c generator.

The collector rings, exciter armature, rotating field, and a fan are mounted on the same shaft which is supported between two bearings. This shaft is driven by a flexible drive spindle which mates directly in the engine-drive spline. A friction damper is incorporated to damp twisting oscillations, thereby reducing spline wear and preventing spindle breakage. The fan provides ventilating air while the aircraft is on the ground and there is no ram air pressure. This gives sufficient cooling for the generator to deliver power at a 25 percent rated load (maximum) continuously.

The stationary member of the generator is made up of the a-c armature and the d-c exciter field. Both a-c and exciter terminal boards are mounted so that they are easily accessible. All brush rigging is located on the generator and is protected with a brush cover. Slotted-hole type mounting provides for ease in attaching to the engine pad. Capacitors connected between the exciter armature terminals and ground suppress radio noise.

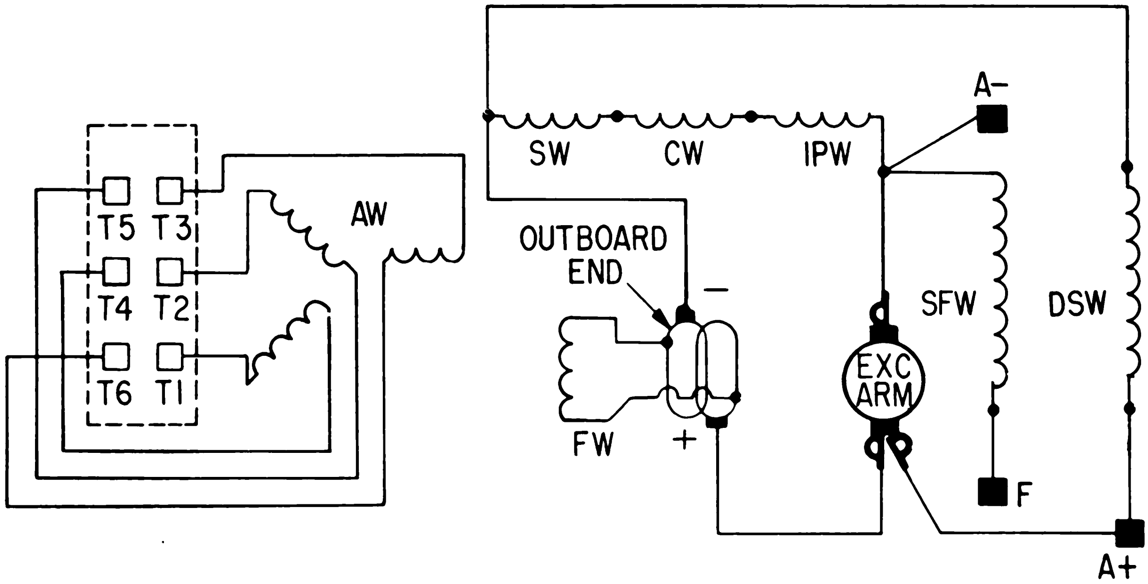
The a-c generator rotating field has 12 poles with adjacent poles being of opposite polarity. One cycle per revolution is produced by each pair of poles; thus, 6 cycles are produced per revolution. The output frequency of the generator varies in direct proportion to the engine-drive speed. A generator operating at 6,000 rpm will be operating at 100 revolutions per second or at 600 cycles per second.

The internal wiring diagram of this a-c generator is shown in figure 7-21.



1. Cover assembly.
2. Collector ring brush.
3. Exciter brush.
4. Collector rings.
5. Exciter commutator.
6. Exciter armature.
7. A-c generator rotating field.
8. Fan.
9. Spindle.
10. A-c armature.
11. Terminal blocks.

Figure 7-20.—Disassembled aircraft a-c generator.



SFW—exciter shunt-field winding.
AW—a-c generator armature winding.
FW—a-c generator field winding.
SW—exciter series winding.
CW—exciter compensating winding.
IPW—exciter interpole winding.
DSW—exciter differential shunt winding.

Figure 7-21.—Internal wiring diagram of a-c generator.

PARALLEL OPERATION

Two or more a-c generators may be operated in parallel with each a-c generator carrying the same share of the load. However, certain precautions must be taken before connecting two or more a-c generators to the same bus. (NOTE: The basic principles of parallel operation of a-c generators, including the methods of synchronizing them, are given in Basic Electricity, NavPers 10086-A.)

Synchronizing, or paralleling, a-c generators is somewhat similar to paralleling d-c generators except that with a-c generators there are more steps. In order to synchronize (parallel) two or more a-c generators to the same bus, it is necessary that they have the same phase sequence and equal voltages and frequencies.

An example of a naval aircraft that utilizes a-c generators in parallel is the P-5A. In this particular aircraft, flight personnel manually synchronize and parallel the generators. The a-c power system of this aircraft is described somewhat in detail since it is typical of large aircraft.

The P-5A utilizes two main engine-driven a-c generators and a third generator that is driven by an auxiliary powerplant (APP). They are rated at 120/208 volts, 3-phase, 400-cycle, 40-kva, 75-percent power factor at 6,000 rpm. The generators are each driven by a main engine through a constant speed drive and blast cooled through a 3-inch diameter air connector at the commutator end. An internal fan, located at the shaft extension, provides sufficient cooling to permit operation at 25 percent of the rating at sea level without blast cooling. With an air-blast equivalent to a total head of 6 inches of water across the generator, it has an intermittent rating of 150-percent load for 5 minutes, and a 5-second rating of 200-percent load. The unit will operate satisfactorily at ±10 percent of rated speed.

These a-c generators are similar to the variable frequency a-c generator just described. The principal difference is that they are designed to work in a constant frequency system; thus, they have a narrow speed range of operation.

In these a-c generators the output of the exciter is delivered to terminals A1 and A2 on

the terminal block. (See fig. 7-22.) Two jumpers connect these terminals to the A+ and A- terminals. The method of connecting the jumpers is shown on the generator instruction plate and is determined by the rotation of the generator. If the jumper connections are not correct, the exciter will not build up voltage.

Leads inside the generator connect the A+ and A- terminals to the slipring brush holders. Leads located in slots in the shaft connect the sliprings to the rotating field windings of the generator. Terminals T1, T2, and T3 of the generator are connected to correspondingly marked terminals on the voltage regulator. Provision is made in the voltage regulators for equalization of the "wattless" component of the load when two or more generators are operated in parallel. Division of the kilowatt load is a function of the governors of the constant speed drive mechanisms which operate the generators.

Phase sequence of the generator is determined by the direction of rotation and the connections from the a-c winding to the terminal block. Reversal of rotation produces a change in phase sequence. It is vitally important that the generators be connected to the line with proper phase sequence, as serious damage to equipment occurs if the phase sequence is incorrect.

The generators are designed to operate at a speed of 6,000 rpm but will operate satisfactorily at any speed between 5,400 and 6,600 rpm.

The constant speed drives are rated at 50 horsepower (hp) and are used to change the variable speed output from the engines to a constant speed to drive the a-c generators. With an input speed between 4,350 and 9,000 rpm (1,400-2,900 engine rpm), drive output speed is 6,000 ±30 rpm stabilized value, under varying conditions of load and speed, and the driven a-c generator supplies power at 400 ±2 cycles per second.

The auxiliary powerplant (APP) affords a compact and lightweight prime source of constant speed power. The unit is a gas turbine, and is designed to drive and cool an aircraft type a-c generator. The unit has a rating of 70-hp continuous and a 5-minute rating of 84 hp at an ambient temperature of 60° F. The nominal 6,000 rpm output speed of the unit is maintained within 5 percent by a governor that regulates fuel pressure to the turbine burners. The governor is set to provide a no-load speed of 6,275 rpm (generator frequency of 418 cycles). An air-bleed control acting on the governor diaphragm is provided at the radioman's station to control the speed at no load from 5,925 to 6,275 rpm, 395 to 418 cycles. A second air valve at the APP, which is in series with the air valve at the control panel, prevents the output speed from being below 5,925 rpm, 395 cycles, at no load, should a break occur in the air-bleed line running between the unit and the a-c control panel.

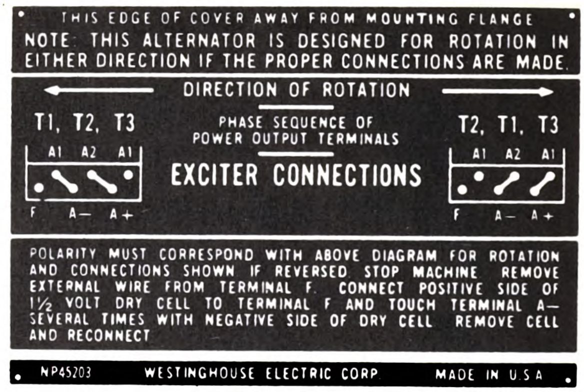


Figure 7-22.—Generator instruction plate, showing proper exciter connections and phase sequence.

An overspeed switch of the rotating, centrifugal type is provided to shut the unit down if the speed should become excessive. The switch is self-resetting, and the APP can be restarted. Other safety devices are provided to insure correct burning and temperatures during operation.

The APP generator drive is not equipped with an overrunning clutch and the unit governor does not include a real load equalizing circuit. Therefore, it cannot be paralleled with a main engine a-c generator.

MAINTENANCE

Generally speaking, the maintenance and testing techniques presented in connection with d-c generators apply to a-c generators. For detailed instructions that are peculiar to a specific a-c generator consult the applicable manuals that are provided for the aircraft and the component.

The following maintenance information will be given since it applies primarily to single-phase inductor type a-c generators and has not

previously been presented. This type a-c generator is a section of an a-c/d-c generator.

With this inductor type a-c generator at no load, the voltages on the generator side and on the load side of the compensating capacitor are the same. At full load (resistance load or equivalent), the voltage on the generator side is higher than the voltage on the load side of the external compensating capacitor. The difference between these two voltages is less at high speed (high frequency) than at low speed (low frequency), because the reactance of the capacitor and the voltage drop (IX_c) across it decrease as the speed and frequency increase. Voltage troubles, if encountered, may be either high voltage or low voltage. High voltage (likely only at light load) indicates a defective regulator (d-c, a-c, or both). Low voltage (at light load or full load) indicates a defective d-c generator, a-c field or armature, regulator, capacitor, or connections. Certain defects (for example, a break in the circuit to the a-c regulator voltage coil) may result in excessive field current, oversaturation, and low voltage, not high voltage.

These generators are not likely to be overloaded, but a defective load (one that is highly inductive, and not the equivalent of resistance load) may result in low voltage, excessive field current, oversaturation, and continued low voltage. Any condition resulting in abnormal field current may result in overheating, which is dangerous not only to the affected generator but the entire system, d.c. as well as a.c.

Corrosion control of generators is the same as for motors/inverters and is discussed in chapter 8 of this course.

EMERGENCY POWER GENERATORS

Many late-model jet aircraft are equipped with ram-air emergency generators. These provide emergency electrical power in the event of main electrical power failure. Some of these are d-c generators and some are a-c generators; a-c systems utilize rectifiers for the d.c. that is required by the aircraft. Different types of emergency power generating systems have been developed, and the manner in which they are installed depends upon the type of aircraft.

In a typical installation the emergency electrical power is provided by a power package which is caused to be positioned outside the aircraft. This occurs when the pilot operates a lever which, through a linkage, pneumatically, or by a spring arrangement, causes the power package to protrude. The ram-air of flight, which is caused by the aircraft's moving through the atmosphere, provides the turning power for the turbine which, in turn, rotates the generator's armature.

The systems are constructed so that the emergency generator will not be placed on the line until its armature is up to speed. This is controlled in different ways; for example, on the F-8E aircraft the pilot places the generator on the line by throwing a switch. He throws this switch after an indicator light comes on, which indicates that the generator's output is up to minimum standards. In the F-4B aircraft the emergency generator is automatically placed on the line by an air-pressure actuated switch. This switch connects the output of the emergency generator to the solenoid of a relay, which will energize when the generator is up to speed. When the relay energizes, it connects the generator to the bus. The aircraft must have an airspeed of at least 190 knots before this switch actuates.

A typical 3-phase emergency generator is shown in figure 7-23 (A). This generator has a capacity of 3 kva, a voltage output of 120/208 volts at 400 ±20 cycles per second, and the output windings are connected wye. The frequency of the output voltage is maintained by the automatic positioning of the variable-pitch blades (fig. 7-23 (B)) and speed regulating section of the ram-air turbine.

The maintenance of emergency generators is similar to that prescribed for other aircraft generators. Since this has already been presented in connection with d-c generators, it will not be repeated here.

Ground testing of some types of emergency generators may be performed while the generator is mounted on the aircraft. When this is done, compressed air from a gas-turbine compressor is funneled onto the turbine blades to drive the generator.

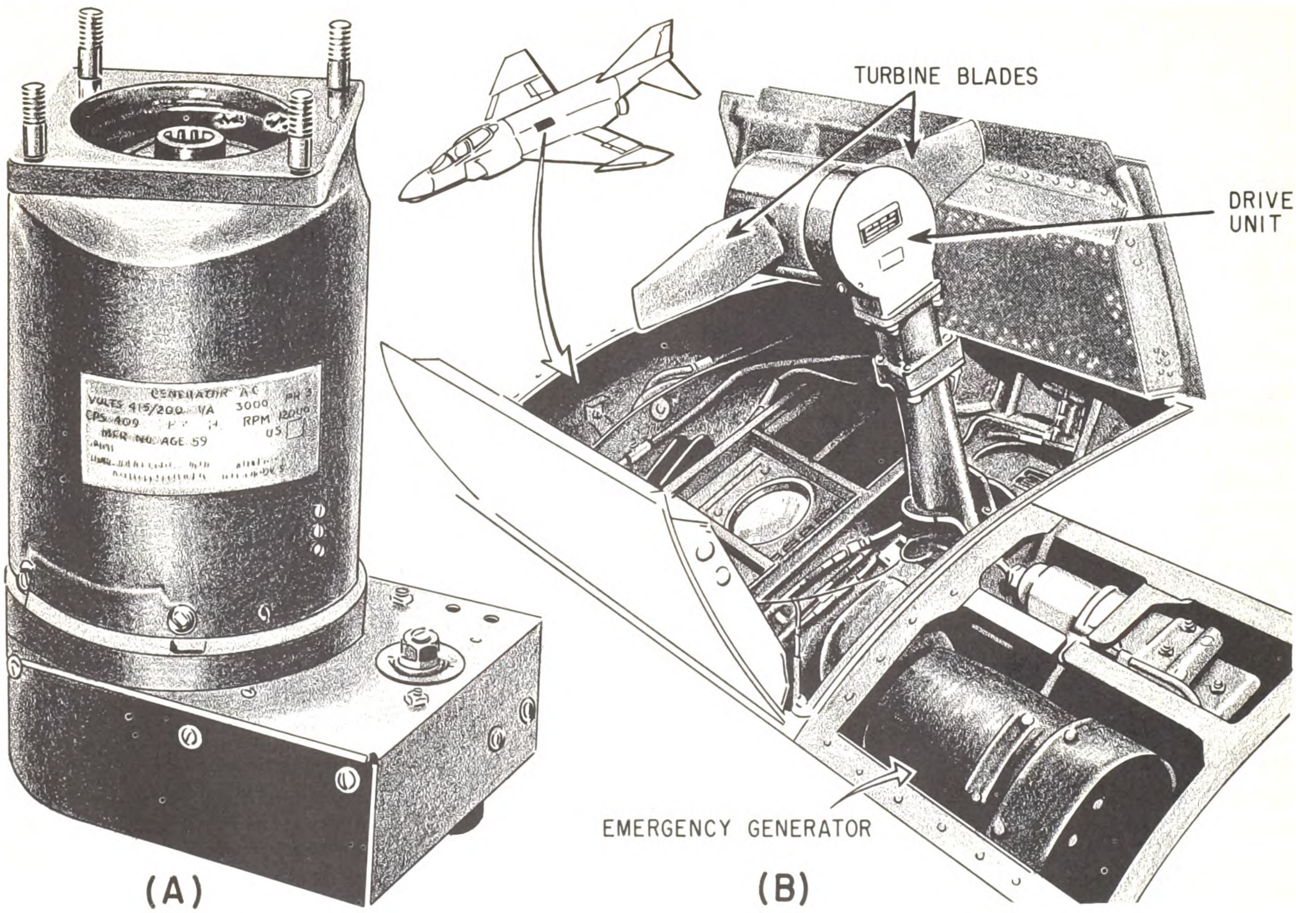


Figure 7-23.—(A) Emergency generator; (B) Typical emergency generator installation.

CHAPTER 8

AIRCRAFT MOTORS AND INVERTERS

A great variety of electric power-drive circuits are employed in the current naval aircraft. The operating units are usually electric motors. In applications where only small movements are required, solenoids are frequently used.

Although the variety of motor circuits is great, certain features are common to the majority. The motors are usually controlled either directly by manual, pressure, or thermostatic switches, or these switches may control a relay which, in turn, opens and closes the motor circuit. Mechanically operated limit switches are used to open a motor circuit when a mechanism has reached its limit of travel in either direction.

Electric motors are used to operate a great number of devices aboard aircraft, including starters, trim tabs, retractable landing lights, electrical variable-pitch propellers, fuel pumps, engine-cowling flaps, deicing equipment, wing-flap mechanisms, heaters, propeller governors, bomb-bay doors, hydraulic pumps, and windshield wipers.

In the past, the great majority of motors used in naval aircraft were d-c motors. However, all aircraft currently in production for the Navy have primary a-c electrical systems; the emphasis now and in the future is on motors of the a-c type.

D-C MOTORS

The three basic types of d-c motors are the shunt, series, and compound. The theory of operation of these motors is thoroughly covered in chapter 16 of Basic Electricity, NavPers 10086-A. A brief summary of each of these motors is as follows:

The motors derive their names from the type of circuit connection between their field and armature windings. The shunt motor employs a high-resistance field connected across the armature. The series motor uses a low-resistance field in series with the armature. The compound motor uses both a high-resistance field in shunt with the armature and a low-resistance field in series with the armature.

The shunt motor has approximately constant speed and widely varying torque. Its speed may be controlled by control of its field current. Decreasing the field current increases the speed of the motor, and at the new speed it will still have constant speed variable torque characteristics. The torque of the shunt motor is less than that of the series motor, and is not normally used in aircraft applications.

The series motor has a widely varying speed and a high starting torque. It is always directly connected to its load because without load it has a dangerous tendency to increase in speed to the point where it disintegrates.

The compound motor has a more stable speed characteristic than that of the series motor and a larger torque than that of the shunt motor. It is used where the combined qualities of the shunt and series motor are required.

In all d-c motors the direction of rotation can be reversed by changing the direction of current flow in either the field or the armature, but not in both at the same time. It is simpler to reverse the current in the field. This is usually accomplished by using a double-pole, double-throw, reversing switch or with a split field and a single-pole, double-throw switch. Figure 8-1 shows a series motor with a split field and a single-pole, double-throw switch. Note that only half the field is used at any one time.

An example of this type of d-c motor is the canopy drive motor shown in figure 8-2. This is a limited-duty motor used to open and close the cockpit canopy. An example of another type of motor assembly, is the actuator shown in figure 8-3. This actuator is used to operate the horizontal stabilizer on some aircraft. It consists

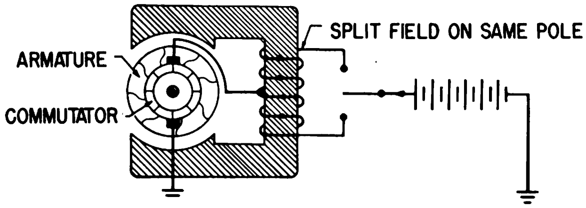


Figure 8-1.—Series-field motor with split field for reversing.

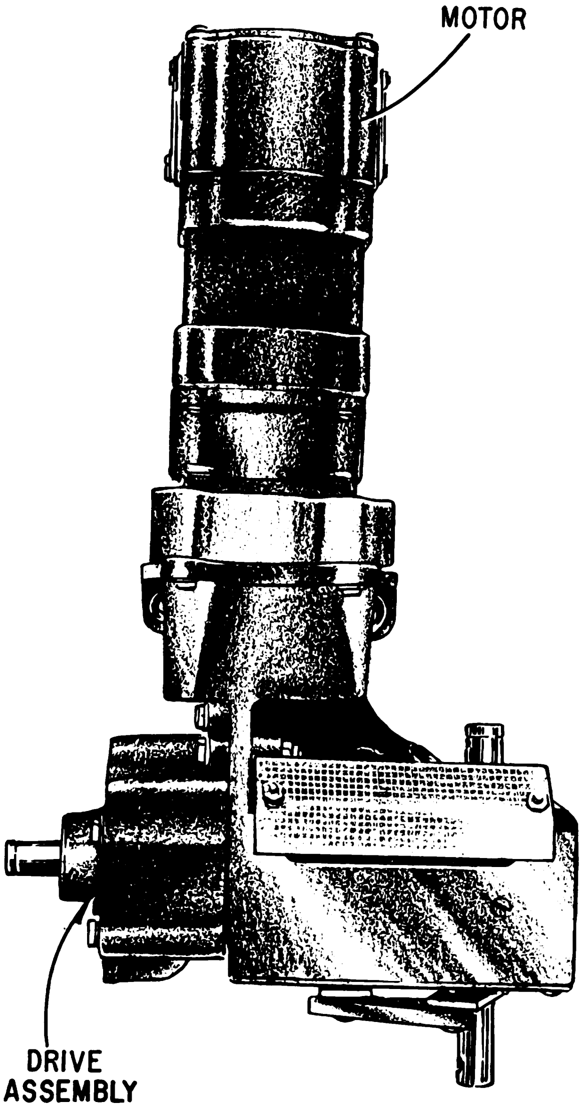


Figure 8-2.—Canopy-drive motor.

of a d-c motor, an a-c motor, and the drive assembly.

OPERATIONAL CHECK OF A D-C MOTOR

Many of the d-c motors used in aircraft are limited-duty type; that is, if they are operated for longer than a specified period of time (for example, 3 minutes), they should be allowed to cool before being operated again. When checking a d-c motor installed on the aircraft, the motor's normal load should be applied. If this is not possible, the motor should be removed and tested in the shop.

PERIODIC INSPECTION

Periodic inspections are conducted on motors as a precaution against motor failure. Insure that the motor is mounted securely. Inspect the mechanical linkage for proper alinement and security. The electrical connections to the motor should be secure and clean. Check for signs of corrosion. See that proper voltage is supplied. Since most motors are installed in sections of the aircraft not accessible during flight, the first indication of motor trouble in many instances is complete failure. When failure occurs or when indications are that the motor is operating improperly, remove the motor for shop inspection.

The condition of the commutator should be determined. Grease or dirt on the commutator causes arcing at the brushes which results in abnormal pitting and wear. The commutator should be cleaned with the recommended solvent; in some cases, the solvent may not do a satisfactory job and it may be necessary to use an abrasive. One that is recommended is No. 0000 sandpaper. If the commutator is found to be burned or pitted either completely or in any localized area, return the motor to overhaul. Brushes should be replaced if they are chipped, cracked, or too short. The amount of wear allowable varies with different motors. In no case should the brush be allowed to wear down to the brush holder. Brushes should slide freely in their holders. If any do not, clean the holders and brushes. If this does not help, replace the brushes. When brushes are removed but are not replaced with new ones, mark them so they can be returned to their original holders; otherwise, they may need to be contoured to insure good commutator contact.

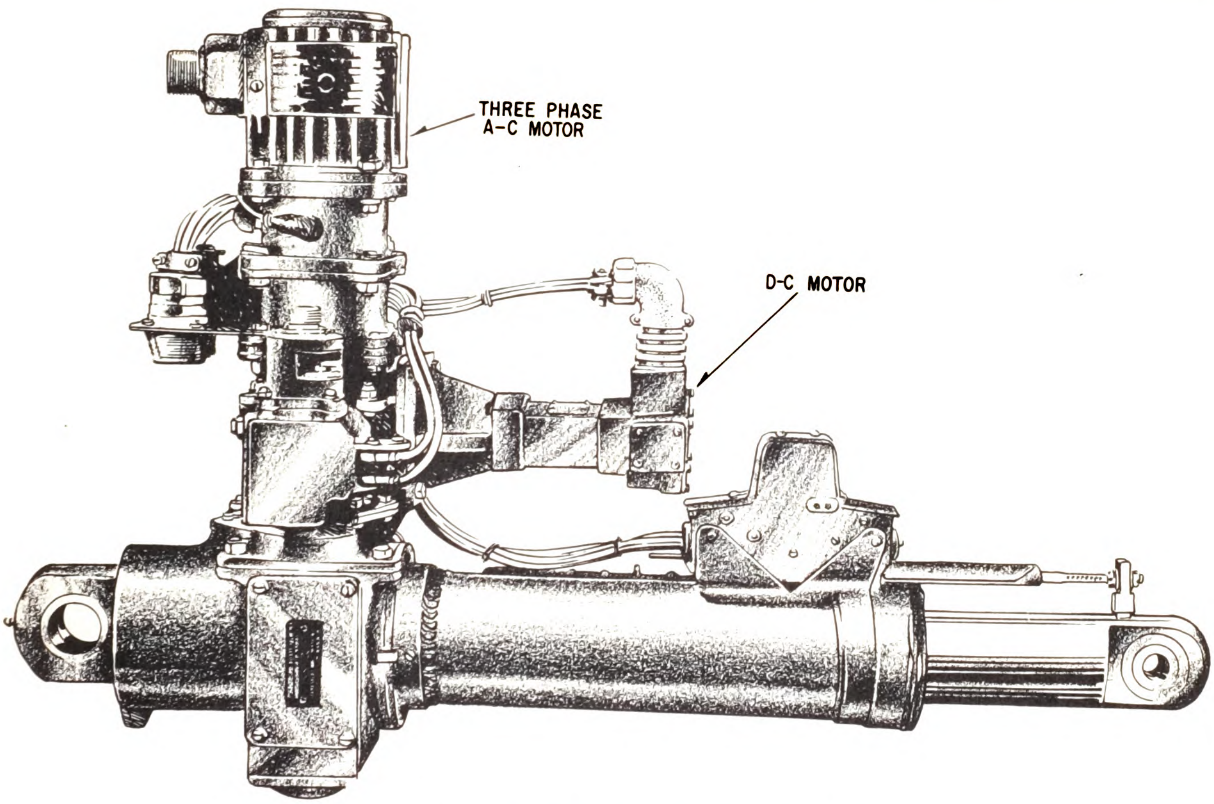


Figure 8-3.—Horizontal stabilizer actuator.

The exposed portion of the windings should be inspected for evidence of overheating. If the insulation on the windings or leads is cracked and brittle, replace the motor. Connect the motor to the proper voltage supply for the final check. If, when the motor is operating, an odor of burned insulation is evident, or if smoke or excessive noise is observed, the motor should be replaced.

When dismantling a motor, the bearings should be removed carefully, wiped clean, and wrapped in clean oil paper until needed during reassembly.

In the inspection of ball bearings, the assembly is slowly rotated. Bearings showing pronounced stickiness or bumpy operation should be replaced. During inspection of bearing assemblies, check for the presence of cracks, pitted surfaces, and any physical damage present in bearing elements.

Antifriction bearings may be either of the ball or the roller types, both of which are widely used in rotating electrical equipment. Many modern electrical motors are equipped with sealed bearing assemblies. The maintenance of these bearings is very easy, since they are prelubricated and require almost no attention during the normal life of the motor in which they are installed. When cleaning motors with sealed bearings, never immerse the sealed bearings in the cleaning solvent. To do so will remove some of the prepacked lubricant.

As a guide to proper maintenance of ball or roller bearings in rotary equipment, the detailed recommendations of the manufacturer as given in the Service Instruction Manual should always be followed. As an example of a general maintenance procedure, consider the following directions, which are taken from the manufacturer's instructions pertaining to a small motor containing standard ball bearings.

The bearings used in this motor normally are replaced with new bearings whenever abnormal conditions occur. However, in the event that replacements are not available, the bearings may be cleaned and relubricated as follows:

1. Wipe the outside of the bearings clean, using a clean cloth.

2. Wash the bearing thoroughly in a cleaning solution (Specification PS-661B).

3. Blow with compressed air until the assembly is dry. Care should be taken not to rotate the bearings while washing or drying.

4. Relubricate by packing the bearing full with the lubricant recommended by the manufacturer.

5. With a clean wooden stick, dig out any grease that can be removed from between the balls on both sides of the bearing assembly. This will leave the bearing about 25 percent full of lubricant, which is the maximum that should be used.

Corrosion control and cleaning of d-c motors are the same as for a-c motors which are discussed later in this chapter.

A-C MOTORS

TYPES OF MOTORS

There are two general types of a-c motors used on aircraft—induction motors and synchronous motors. Either kind may be single-phase or 3-phase. Three-phase induction motors are used where larger amounts of power are required. On aircraft they are used to operate such devices as flaps, landing gears, fuel pumps, and hydraulic pumps. Single-phase induction motors are used to operate devices such as the surface lock, the intercooler shutter, and the oil shutoff valves, where the power requirement is low.

Three-phase synchronous motors operate at speeds which depend on the frequency of the applied power; they are used to operate gyroscopes in certain instruments and propeller synchronizer systems. Single-phase synchronous motors provide power to operate tachometer indicators, electric clocks, and other small precision equipment. They require some auxiliary method to bring them up to synchronous speeds—in other words, to start them. The use of synchronous motors is limited on aircraft.

The induction motor is most commonly used on aircraft having a-c power systems. The induction motor has certain advantages over d-c motors. It is simpler in construction and also more rugged and durable than d-c motors of comparable ratings.

The theory of operation of a-c motors is discussed in Basic Electricity, NavPers 10086-A.

MAINTENANCE OF A-C MOTORS

Due to the simple construction of a-c motors, very little actual maintenance is required. An inspection of the motor for proper security of mounting and proper alignment of mechanical drive end is necessary. Check all connections for proper voltage, security, and absence of corrosion. A simple continuity check of the fields will usually be sufficient for checking for shorts, opens, or grounds.

Most a-c motors are prelubricated at the time of manufacture and are equipped with sealed bearings. The bearings require a visual inspection only. If they are found to be damaged, return the motor to overhaul. Before reassembling, wipe the rotor and stator clean; this can be accomplished by using a lint-free cloth that has been dampened with the recommended cleaning solvent. As a final check, conduct a preinstallation operational check of the motor using the proper voltage and phase connections.

Rotating machinery should be inspected and cleaned at prescribed intervals (periodic checks) and whenever repairs to the machinery have been made.

Corrosion preventive maintenance of rotating machinery includes the following functions:

1. An adequate cleaning program.
2. Thorough periodic lubrication.
3. Detailed inspection for corrosion and failure of protective systems.
4. Prompt treatment of corrosion and touchup of damaged paint areas.

An effective program of protection starts with a positive and continuous cleaning schedule. There is no single cleaning agent or process that will clean all types of parts. A cleaning agent that will clean one set of parts will not clean another, or it may attack the alloys or metal comprising the other set. Therefore different cleaning agents are necessary and selection of these agents will vary for different surfaces and equipment. The choice of cleaning agents and the correct process can generally be satisfactorily made by considering the following points:

1. Composition of the part.
2. Nature of the surface of the part.
3. Complexity of construction.
4. Type of contaminations to be removed.
5. Degree of cleanliness required.

In addition to Stoddard solvent (PS-661B) another approved solvent for cleaning electrical and electronic equipment is inhibited methyl

chloroform (trichloroethane). This new solvent should be used for cleaning applications in which carbon tetrachloride was previously used. Even though it is nonflammable and less toxic than carbon tetrachloride, methyl chloroform does present some hazards to personnel and insulation. (See BuShips Technical Manual, paragraphs 60-413 and 67-306.)

Methyl chloroform is slightly more severe than carbon tetrachloride on insulation which deteriorates proportionally to the amount of time exposed to the solvent. After 5 minutes, methyl chloroform will noticeably soften varnishes and reduce dielectric strength and abrasion resistance. A continuous immersion of 1 hour will completely destroy the properties of most insulating materials and varnishes used in armatures, field coils, and similarly constructed electrical components. Glass melamine and laminated phenolics, however, are only slightly affected by such immersion.

Methyl chloroform itself is nonflammable, but, after 90 percent evaporation, the residue contains a high percentage of the flammable inhibitor. When the solvent has been allowed to evaporate from containers, the flammability of the residue should be recognized.

Special precautions when using methyl chloroform are:

1. Avoid prolonged or repeated breathing of vapor or contact with the skin. Do not take internally.
2. Prevent contact with open flame, because highly toxic phosgene may be formed.
3. Immerse electrical equipment less than 5 minutes, because prolonged immersion will destroy the properties of most insulating materials.
4. The solvent should be first tested on a portion of the item to be sure it will not remove, blister, or otherwise damage the material.
5. Do not use on oxygen equipment—the inhibiting agent is flammable.
6. Do not use on hot equipment—The accelerated evaporation will increase the toxic hazard.
7. Use with adequate ventilation.

Additional material on the use of solvents in cleaning electrical and electronic equipment is contained in chapters devoted to the maintenance of such equipments in the BuShips Technical Manual.

One fundamental factor of corrosion prevention is the effect of the geographical location of the equipment. The location in which the aircraft is operating determines the amount of exposure to salt water, moisture condensation, temperature conditions, and the amount of soil and dust in the atmosphere. Scheduled Maintenance Requirement Manuals should be used as general guides when inspecting for corrosion.

Through experience it will be learned that most aircraft have trouble areas where corrosion will set in despite routine inspection and maintenance requirements. These trouble areas may be peculiar to particular aircraft models, but most aircraft operating in a marine environment are found to have similar conditions.

In addition to routine maintenance inspections, the following special requirements should be observed:

1. For ship-based aircraft, or for amphibious aircraft or seaplanes, a daily check should be made and critical areas wiped down or treated as necessary.
2. Shore-based aircraft operating in a salt, moist atmosphere should be given a special check at least once a week.
3. All aircraft held in static storage in preserved condition should be inspected in accordance with the applicable requirements of Preservation of Naval Aircraft, NavWeps 15-01-500.

The AE should become familiar with technical manuals relating to the prevention and treatment of corrosion. Applicable manuals for specific aircraft and equipment and Corrosion Control for Aircraft, NavWeps 01-1A-509, should be consulted before commencement of work on the corrosion control and cleaning of rotating machinery. Before work on a specific motor or generator is started, the AE should consult the Overhaul Instruction Manual for that particular unit.

INVERTERS

Current Navy aircraft use alternating current as the primary source of electrical power. The inverter is an important part of these systems. The present standard is the 115-volt, 3-phase, 400-cycle a-c system. This power is taken from a 4-wire system. The 4-wire system is advantageous because it allows a greater choice of single-phase circuits, balancing of the phase loads is improved, it is less vulnerable to power failure, and better frequency and voltage control is obtained.

Figure 8-4 shows the functional flow diagram of a modern helicopter electrical system. The system is shown in order to familiarize the AE with the manner in which the various power equipments are connected to facilitate power distribution under either normal or emergency conditions. In the explanation that follows, attention is invited to the part dealing with the inverter.

The electric power supply system (fig. 8-4) provides 120/208-volt, 400-cycle, 3-phase a-c power; 26-volt, 400-cycle, single-phase a-c power; and 28-volt d-c power to operate the various electrical and electronic components of the helicopter. The electrical power supply system is considered to end at the distribution buses in the circuit breaker and fuse panel. The circuit breakers and fuses are considered to be a part of the using systems which they serve.

There are three sources of electrical power: the number 1 generator, the number 2 generator, and the battery. In addition, external power receptacles are provided for both a-c and d-c power. Power from these sources is distributed through a multibus system.

The principal source of electrical power for the aircraft is the number 1 (a-c) generator, supplying power directly to the 120/208-volt a-c primary, monitor, and inverter buses and the 28-volt converter. Both the primary and monitor buses, in turn, supply power to two transformers. One of the transformers supplies the appropriate power to the 26-volt a-c inverter and primary buses and the lighting bus, and the other supplies the necessary power to the 26-volt a-c monitor bus. The 28-volt converter converts the a.c. to d.c. and supplies power to the 28-volt d-c primary and monitor buses and charges the battery.

A second source of power is the number 2 generator which, under normal conditions, supplies power to the 120/208-volt a-c number 2 generator bus. In the event of failure of the number 1 generator, the number 2 generator will automatically take over and supply power to the system in the same manner as did the number 1 generator with one exception—power to the 120/208-volt a-c monitor bus and the 26-volt a-c monitor bus will be cut off. In the event of failure of only the number 2 generator, the number 1 generator will supply power to the entire system. If both generators fail, power will be supplied automatically from the battery to the 28-volt d-c primary bus, to the lighting bus and to the inverter. The inverter will then change the d.c. to a.c. and supply the necessary power to the 120/208-volt a-c inverter bus and to the 26-volt a-c inverter bus. In this situation, power to all other buses will be cut off. The changeovers are accomplished automatically by means of automatic transfer relays and power failure relays. Any undervoltage, overvoltage, or underfrequency condition in the generator output will cause the automatic changeover to occur.

Because of such wide variety in the types and makes of inverters that are installed on aircraft, it is impractical to describe all of them in this course. However, two inverters are described somewhat in detail. The information that applies to these will in most cases apply to most inverters that the AE is required to maintain. For detailed information about a particular inverter, refer to the manuals on that inverter.

Inverters operate on the same electrical principles as d-c motors and a-c generators. These have been treated in Basic Electricity, NavPers 10086-A, and hence are not discussed here.

TYPICAL INVERTERS

In most inverters the d-c armature and the a-c generating field windings are wound on the same rotor shaft while, the d-c motor field and generator output (armature) windings are wound on the stator. A control box is attached to many inverters which contains the necessary devices to control its operation. These devices consist of the operating relays, voltage regulator and rectifier, filtering units, and smaller circuit components.

The d-c motor of most aircraft inverters is essentially a shunt-wound motor. High starting currents and a low rate of acceleration (due to low torque at starting) are characteristic of shunt-wound machines. To avoid the effects of these undesirable characteristics on other portions of the aircraft's d-c system, the larger inverters employ a series starting winding. When the machine approaches its normal rated speed, relays disconnect the series starting winding and connect the d-c input directly to the d-c motor armature and the shunt winding. The machine then operates as a shunt-wound motor which has desirable constant-speed characteristics. In some machines, small compensating and commutating pole windings are used in series with the motor armature, but these windings have no effect on the shunt-motor action.

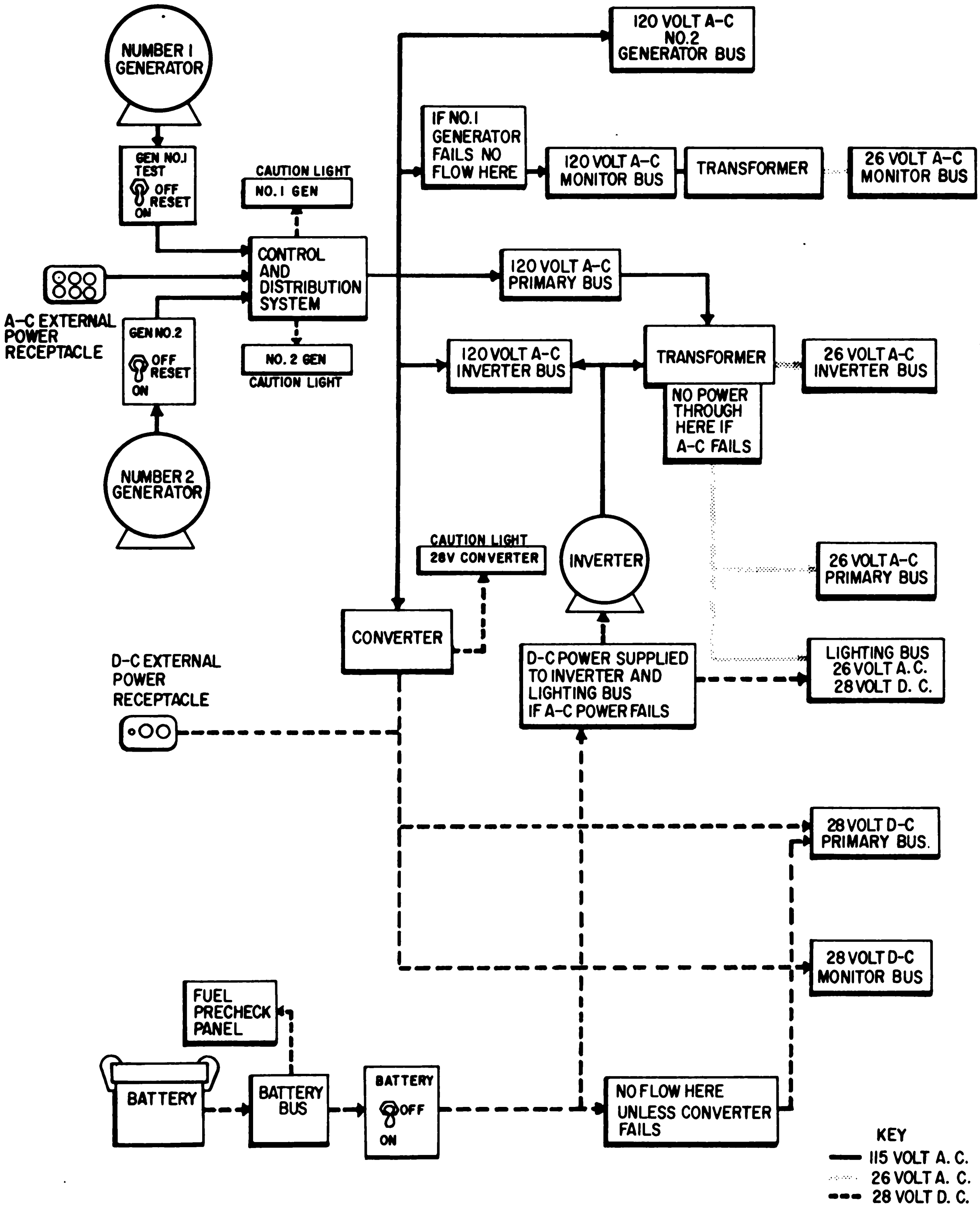


Figure 8-4.—Electrical power supply functional flow diagram.

The d-c motor converts electrical energy into mechanical energy to drive the generator. The d-c load current drawn by the motor depends on the a-c load on the generator. The motor speed is controlled by a speed control governor. In most cases, the speed control governor is a device which automatically varies a resistance in series with the motor shunt field. The speed of a d-c motor is inversely proportional to the strength of the field. Therefore, the speed governor automatically decreases the resistance of the shunt field as the motor tends to speed up, and a greater shunt-field current is allowed to flow in the shunt windings, thus reducing the speed. As the motor speed tends to fall below its normal value, the shunt-field resistance is increased, less current flows in the shunt-field windings, and the motor speeds up.

The generated a-c voltage is proportional to the speed of the rotor and the strength of the generator rotor field flux. The controlled frequency of the a-c output is usually fixed at 400 cps. This frequency is a function of the number of poles in the generator field and the speed of the motor. The number of independent voltages, or phases, in the output is determined by the number of sets of windings on the stator of the generator. In some inverters, both 3-phase and single-phase outputs are obtained from the same machine; others are equipped to supply only one type of output—either single-phase or 3-phase.

The output voltage ratings of aircraft inverters vary considerably depending on the type of aircraft in which the machine is installed and the equipment which it supplies. For example, a number of inverters may be installed in the same aircraft. One may be designed to supply 26 volts of single-phase alternating current to an essential bus during emergencies. Another may be used continuously to supply 115 volts of single-phase a-c power, while still another may be used to furnish 115/200 volts of 3-phase power to a specified bus or equipment.

The output voltage of the machine is usually maintained at an almost constant value by controlling the d-c excitation current in the rotor field of the generator. In most cases this is accomplished by means of a carbon-pile voltage regulator which is controlled indirectly by the terminal voltage. Variation in the output level of the terminal voltage changes the variable resistance of the carbon pile, which is in series with the generator field, thereby changing the excitation of the a-c generator field. In turn, the terminal voltage is regulated.

A cutaway view of a typical high-output aircraft inverter is shown in figure 8-5.

THREE-PHASE INVERTERS

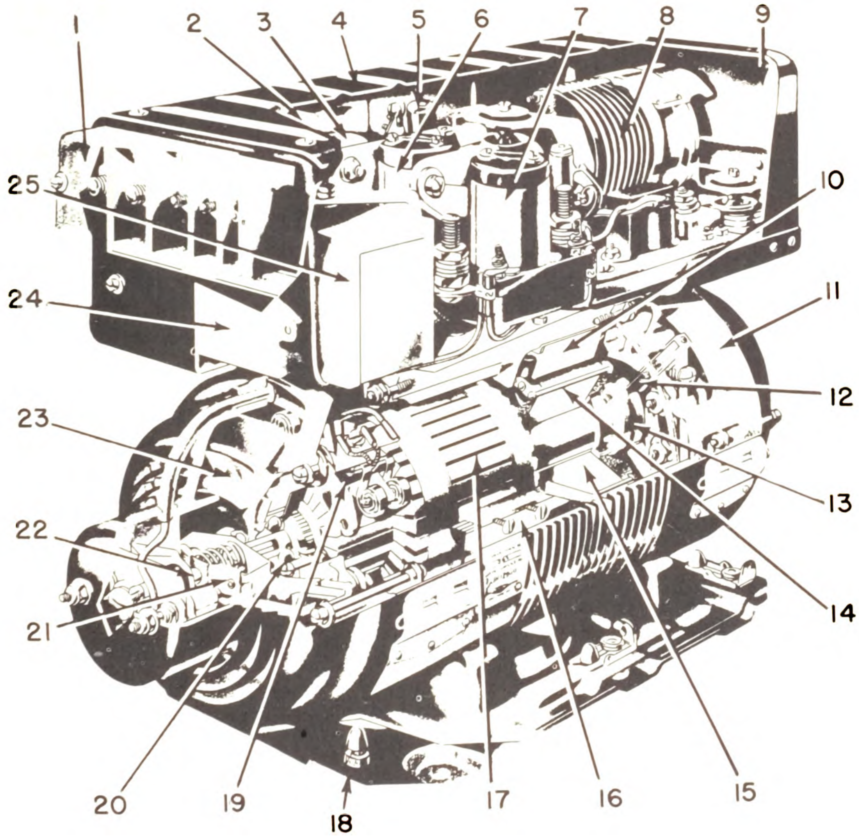
Figure 8-6 is a simplified schematic diagram of a typical inverter similar to the one shown in figure 8-5. The 3-phase alternating current at 115 volts may be obtained across the delta-connected output terminals when approximately 27.5 volts of direct current are applied across the input terminals of the motor.

When d-c input voltage is applied and the main control switch is closed, the input voltage then appears at point A and the coil of the starting relay becomes energized, closing its contacts. The input is then connected directly to point B and the direct current flows through the d-c motor and its series field, starting rotation of the motor. The large voltage drop across BC, which is due to a high series-field current, energizes the coil of the lower running relay (1, fig. 8-6), and causes its normally closed contacts to open. As the motor approaches its operating speed, series-field current decreases, thereby decreasing the voltage drop across BC. The relay is deenergized, and its contacts close.

When the contacts of the first running relay (1) close, the voltage at the positive brush of the d-c armature is then applied to the coil of the second running relay (2). This voltage is sufficient to energize the coil of the relay (2), its contacts close, and input voltage is then applied directly to the d-c armature and the shunt field, bypassing (shorting out) the series starting field. The motor then operates as a shunt-wound machine.

When the starting relay is energized, the input voltage at point B also serves to excite the rotating field of the a-c generator through sliprings located on the rotating shaft. Since the generator field is in series with a carbon-pile unit of the voltage regulator, the direct current through the rotor is thereby controlled. The rotating field flux sweeps across the stationary armature windings and induces voltages in them, and 3-phase a-c voltage appears across the output terminals.

A portion of the output current (output terminal A) is rectified through the stepdown transformer and dry-disk full-wave rectifier. The rectified direct current then regulates the current flowing in the generator rotor field by its action in the operating coil of the regulator. The action of the carbon-pile regulator is the



1. Terminal block.
2. Clare relay.
3. Output relay.
4. Control box cover.
5. Resistor.
6. Running relay.
7. Starting relay.
8. Voltage regulator.
9. Control box.
10. Generator stator.
11. Motor generator casting.
12. Generator brushes.
13. Generator sliprings.
14. Field conductor bars.
15. Generator field.
16. Motor yoke.
17. Motor armature.
18. Subbase.
19. Motor brushes.
20. Ball bearing.
21. Centrifugal governor.
22. Carbon pile.
23. Centrifugal fan.
24. Capacitor unit.
25. Filter unit.

Figure 8-5.—Cutaway view of aircraft inverter.

same as that for any d-c carbon-pile regulator. The voltage-adjusting rheostat is used to set the operating level of the output.

A functional diagram of a typical speed control governor is illustrated in figure 8-7. The governor consists of two main parts, the rotating portion, which is mounted on the motor end of the d-c armature shaft, and the stationary portion mounted on the end cover of the inverter housing. The motor shaft is extended axially by a coil spring (rotor spring). Centrifugal weights mounted on a leaf spring oppose the action of the rotor spring. The stationary portion of the governor consists principally of a carbon pile, a stator spring with its adjusting screw, and a pressure shaft. As shown in the diagram, the

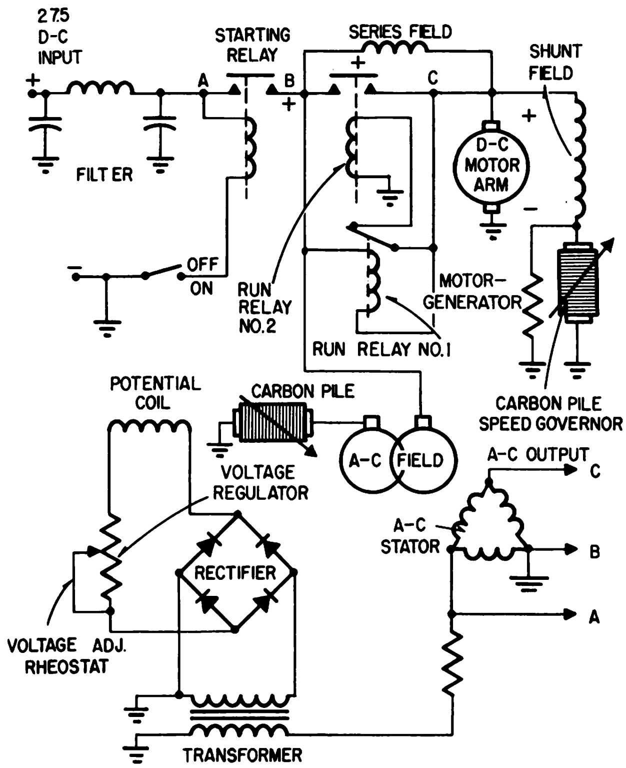


Figure 8-6.—Simplified schematic of an aircraft inverter.

pressure shaft extends through the center of the carbon pile with its inner length greater than the length of the carbon pile.

When pressure is applied at either end of the carbon pile, its resistance is decreased. When the generator is at rest, or rotating at low speed, the centrifugal weights are positioned as shown with the rotor spring holding the carbon pile at high compression (low resistance) by heavy pressure against the left end of the pile. Minimum resistance results in maximum field current, which gives maximum field flux for good starting characteristics. The force of the stator spring is overcome by the rotor spring action.

As the motor approaches its operating speed, the centrifugal weights on the leaf spring move outward, compressing the rotor spring, and reducing the pressure on the left side of the pile. The resistance of the pile increases with the reduction of pressure until the right end plate of the pressure shaft comes into contact with the pile. Any further movement of the centrifugal weights above or below the normal operating speed will then cause pressure to be exerted against the right end of the pile. This movement either aids or opposes the action of the stator spring.

If the motor speed tends to increase above the normal operating speed, the weights move outward, the rotor spring is further compressed,

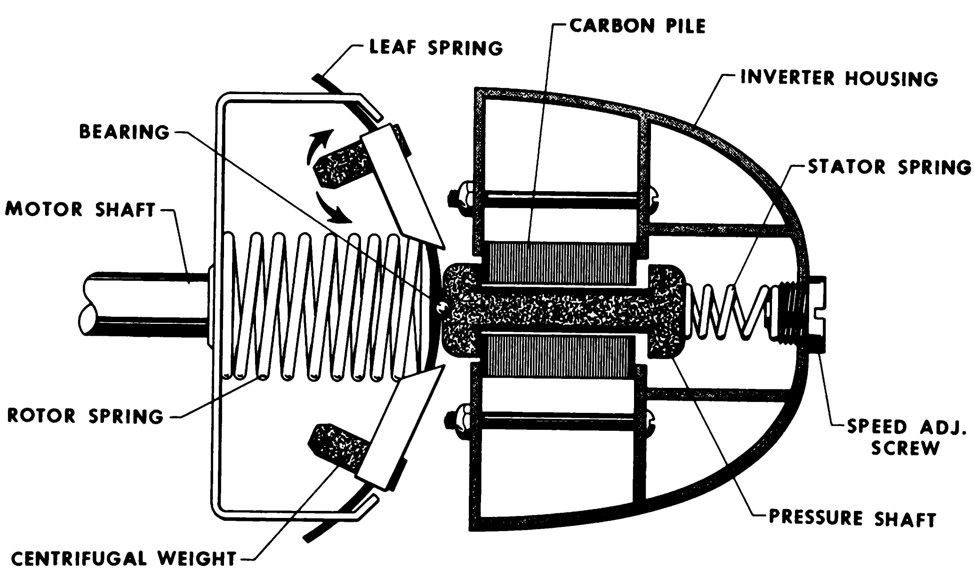
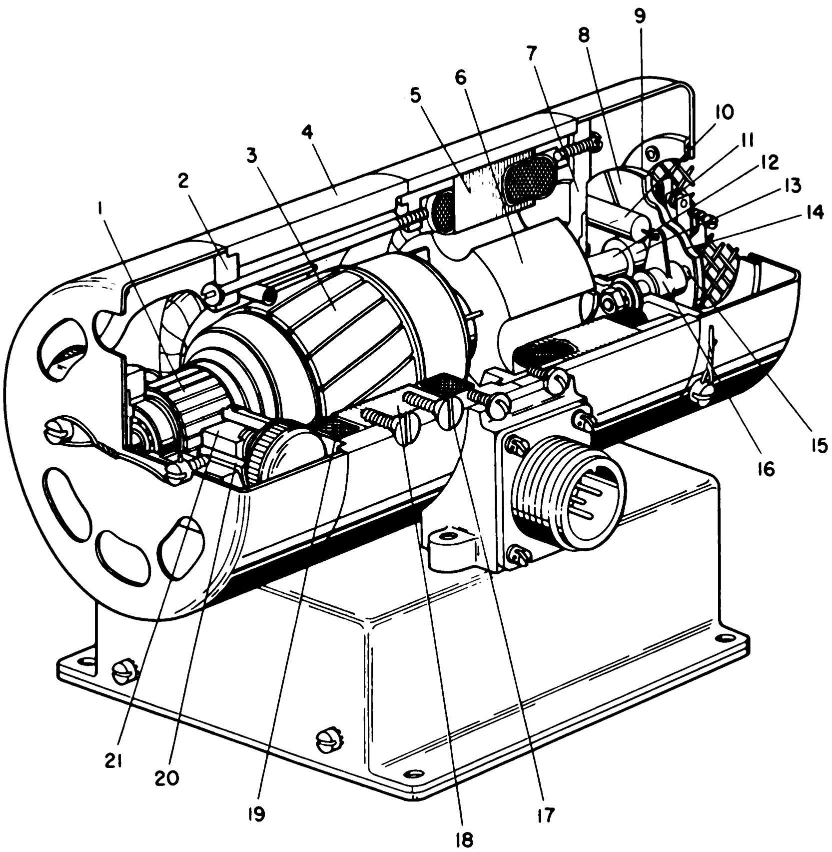


Figure 8-7.—Typical speed control governor.

and the pressure shaft moves to the left, due to the force of the stator spring. More pressure is exerted on the right end of the pile, the pile resistance decreases, and more current flows in the motor shunt field, increasing the field flux. Increasing the field flux of a d-c motor decreases the speed; therefore, the speed of the motor is reduced. Conversely, if the motor tends to slow down below its operating speed, the weights move inward, the action of the rotor spring opposes the action of the stator spring, and the pressure shaft moves to the right. Because of the greater length of the pressure shaft, no pressure is exerted on the left end of the pile; thus, the pile resistance increases, field flux is reduced, and the motor speeds up.

INSTRUMENT TYPE INVERTER

A cutaway view of the instrument inverter used on P-2H aircraft is shown in figure 8-8. Inverters of this type do not produce as high an



1. Commutator.
2. Bearing bracket.
3. Armature.
4. Housing.
5. Stator core.
6. Rotor.
7. Bearing bracket.
8. Sliprings.
9. Insulator disk.
10. Capacitor.
11. Contacts.
12. Shaft.
13. Bushing.
14. Speed governor.
15. Brushes.
16. Brush holder.
17. Screws.
18. Pole shoe.
19. Field coil.
20. Commutator brush holder.
21. Commutator brush.

Figure 8-8.—Cutaway view of an E1616-2 inverter.

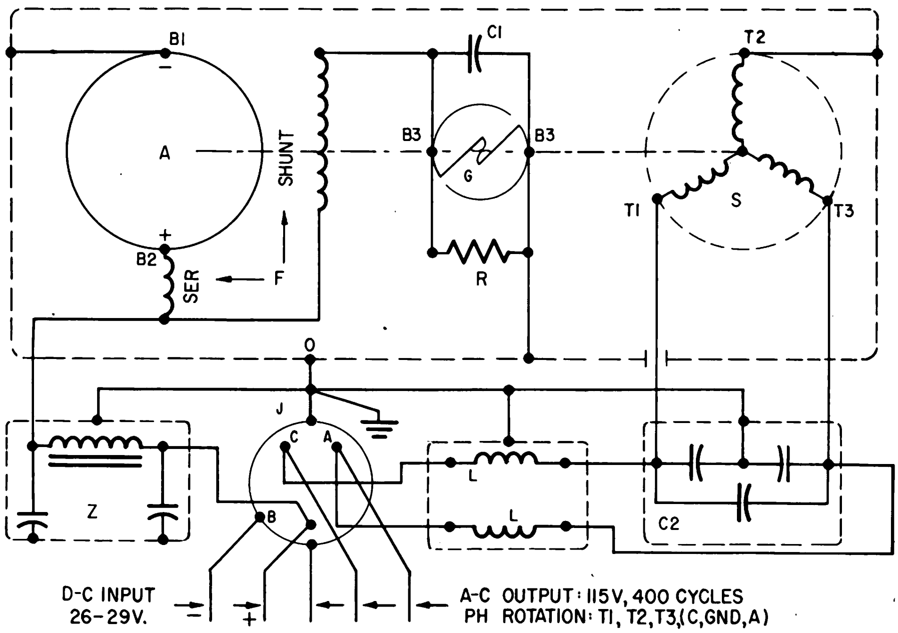
output as the type just discussed and are smaller in physical size. You should make frequent reference to figure 8-8 (cutaway view) and figure 8-9 (wiring diagram) when studying the operation of this inverter. Each major component of the inverter is discussed.

Motor

The motor operates from direct current and is a compound wound type; that is, it has one set of field coils connected in parallel with the armature and one set of field coils connected in series with the armature. The compound winding provides high starting torque for low temperature operation.

The direct current divides into two branches. One branch passes through the motor shunt-field coils; the other passes through the series-field coils and armature coils. Each of these circuits is completed to ground. The current through the shunt and series coils and the armature coils sets up magnetomotive forces which produce a torque in the armature, causing it to rotate.

The d-c input is brought into the series windings of the field coil assembly (19, fig. 8-8). It flows through the windings and into the commutator brush holder (20) and brush (21). Since the



A—Armature assembly.
B1 and B2—Commutator brush assemblies.
B3—Governor brushes and shunts.
C1—Governor noise suppressing capacitor.
C2—Output voltage correcting and RF filtering capacitor assembly.
F—Field coil assembly.
G—Speed control governor.
J—Electrical connector receptacle.
L—RF output filter chokes.
O—Ground.
R—Governor point resistor.
S—Generator stator assembly.
Z—RF input filter assembly.

Figure 8-9.—Internal wiring diagram.

positive brush and negative brush contact the commutator (1), the input current flows from the positive brush, through the armature (3) coils, and into the negative brush and brush holder. Both the negative brush holder and the negative side of the power supply are grounded. The series combination of shunt-field windings and speed governor is connected in parallel with the series combination of armature coils and series-field windings, and draws energizing current from the d-c input power supply. Motor speed, which determines the a-c output frequency and voltage, is controlled by a resistor in series with the shunt field at ground potential. The resistor is cut in or shorted out of the shunt-field circuit by contacts (11) of the centrifugal governor (14) mounted on the rotor (6) end of the shaft (12).

Field Coils

The field coil assembly (19) consists of two field coils. Each is placed around a laminated pole shoe (18) which is secured by two screws (17) to the inside of the steel cylindrical housing (4), forming the magnet circuit. The series and the shunt windings are wrapped together in the same coil.

Motor Armature

The motor armature (3) consists of a core, windings, insulation, and the commutator (1), mounted on the shaft (12). The core is made up of a stack of slotted iron laminations held tightly together and anchored to the shaft. The armature winding consists of coils wound in the slots of the core. The ends of the coils are connected to the commutator segments. The shaft rotates in two greasepacked ball bearings, mounted in the two bearing brackets (2) and (7).

Speed Governor

The speed governor assembly (14, fig. 8-8) consists of two sliprings (8), an insulator disk (9), and two contacts (11). Each of the sliprings is a semicircular copper disk. They are both attached to the insulator disk, but do not contact each other. The insulator disk insulates the two sliprings from each other and also from the metal bushing (13) which contacts the shaft (12). Two brushes (15) contact the sliprings. One of the brush holders is grounded. The other brush holder (16) is insulated from ground. The shunt field is connected to the ungrounded brush holder. The ungrounded brush holder is connected through brush (15) and slipring (8) to one of the contacts (11). The other contact is grounded through the opposite slipring and brush. A resistor is connected across the sliprings, in parallel with the contacts.

Resistance in series with the shunt-field circuit decreases magnetic field strength and increases motor speed. Decreased resistance in the shunt-field circuit lowers motor speed. The position of the governor contacts with respect to each other determines the path of the shunt-field current and the strength of the magnetic field at any instant. The path may be either through the resistor or through the governor contacts and sliprings, the latter path having a relatively low resistance compared to the resistor. By this means resistance is either added to the shunt-field circuit or removed from it, and the motor speed is controlled.

When the spring-mounted contacts of the governor are closed, shunt-field current flows from one slipring to the other and the resistor is shorted out. The governor contacts open and close by centrifugal action. At rest, the contacts are in a closed position and the resistor is shorted out to result in full field strength and large starting torque when line voltage is applied to the motor. Motor acceleration is rapid, and when rotation begins, the contacts tend to open but do not actually separate until 5,000 to 7,000 rpm speed has been reached. The outer spring is weaker than the inner spring. When speed exceeds 5,000 to 7,000 rpm the outer spring is forced away from the inner by centrifugal action, causing the contacts to open and remove the short on the resistor.

The field current is thereby reduced and the magnet flux weakened, resulting in armature speed acceleration and creating additional centrifugal force on the springs. The contact on the inner spring is forced toward the contact on the outer spring by the increased speed. Movement of the latter is limited by the preadjusted screw top. At approximately 12,000 rpm the contact on the inner spring touches the contact on the outer spring, thus again shorting out the resistor, strengthening the field and tending to reduce the motor speed. The speed does not, however, drop noticeably within the specified input voltage limits because the action is repeated rapidly to give a high degree of speed stability and minimum hunting effect. Figure 8-10 illustrates the action of the governor contact.

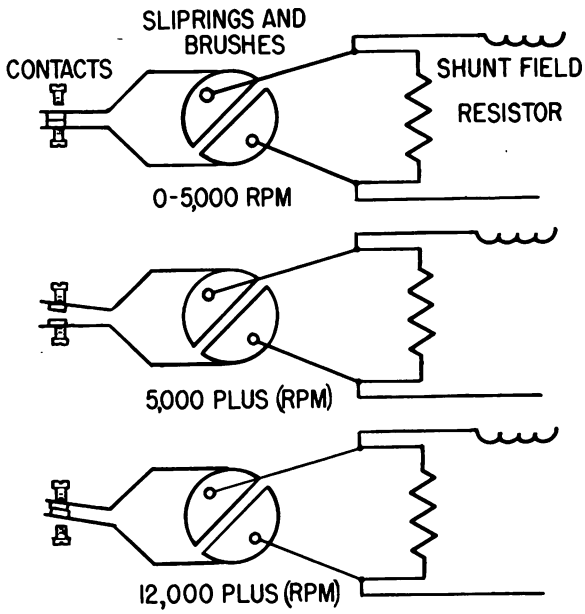


Figure 8-10.—Action of governor contacts for controlling motor speed.

Generator

The generator consists of a 4-pole permanent magnet rotor (6, fig. 8-8) rotating within a 3-phase stator.

The permanent magnet creates a fixed magnetic flux in the stator core (5) when it is at rest. When the armature revolves, causing the rotor to revolve, the magnetic flux also rotates at the same rate, and cuts the conductors of the stator winding, inducing voltage in it. In a 2-pole generator, the induced voltage causes current to flow in one direction for one-half revolution of the rotor and in the opposite direction for the other half of the revolution, thus completing one cycle. In the generator of this inverter, which has 4 poles, the induced voltage changes the direction of flow 4 times, completing 2 a-c cycles per revolution. The frequency of the inverter generator voltage is determined by the speed at which the rotor magnet rotates.

The generator stator coils are 3-phase, Y-connected. They consist of 3 groups of coils connected 120 electrical and mechanical degrees apart. Therefore, 3 separate voltages are brought out through 2 leads, plus the stator frame, which is used as the third and grounded lead.

Filters

There are five filters in the inverter; a capacitor (10, fig. 8-8) across the speed governor brushes, a capacitor assembly, a filter assembly, and two RF chokes in the filter box. The capacitor (10) suppresses electrical disturbances created by the "make and break" action of the governor contacts. The RF chokes and the capacitor assembly suppress RF disturbances originating in the inverter from the a-c output circuits. The capacitor assembly also functions as a power factor corrector to adjust the output voltage to the required value. The input filter assembly consists of two capacitors and a choke. It prevents RF disturbances which may exist in the d-c input line from entering the inverter, and also prevents RF disturbances created by the inverter operation from being transmitted to the d-c input line.

Operation

The operation of the inverter is entirely automatic. There is no starting switch, load switch, fuse or circuit breaker, or other disconnecting device included in the inverter. Such auxiliaries are usually part of the equipment with which the inverter operates, or are included in the external power control circuits.

MAINTENANCE AND TESTING

Information given in chapter 7 in connection with generator maintenance is applicable to inverters and is not discussed here. The information that is given here is to acquaint you with what should be done with respect to periodic inspections of aircraft inverters in order to improve their performance and lengthen their life.

Prior to installing an inverter in an aircraft, a complete test should be run utilizing the aircraft generator test stand and test assembly load bank (figs. 7-13 and 7-14) in order to insure operation conforming to that described in applicable manuals.

The intervals between various maintenance checks differ from one inverter to another. However, it is recommended that output voltage and frequency inspections in aircraft be made after every 60 hours of operation and bench checks after every 120 hours. Inverters should undergo a preflight inspection prior to each flight. The applicable Overhaul Instruction Manuals should be used as a guide in determining

exact voltage, frequency tolerance, and so forth, during these tests.

Except for the bench check, all inspections and tests may be performed with the inverter installed on the aircraft. A brief description of each type of check is as follows.

Output Voltage and Frequency

Perform an operational check on each phase for voltage, and a frequency check on any one phase, under normal load and no load condition; adjust as necessary. Voltage adjustment on the regulated phase should be 115 volts and should provide for a voltage spread of not more than 10 volts between the low and high voltage on all phases as measured with an accurate a-c voltmeter.

Frequency adjustment should be as near as possible to the optimum setting, which on the majority of inverters is 400 cycles.

Brushes

Check brushes for freedom of movement in the brush holder, condition of pigtails for fraying, burning, looseness and melted solder where pigtails are joined in a common terminal; check brushes for evidence of wear beyond permissible limits, cracking, breaking, burning, chipping, and nonuniformity of wear as compared to normally worn brushes; check spring tension. Worn or defective brushes require the inverter to be replaced. When new brushes are installed, the run-in procedure outlined in the applicable equipment manual should be followed.

Terminals and Shock Mounts

Check all terminals and connections for tightness and corrosion. Inspect all shock mounts for wear, chafing, and deterioration. Replace as necessary.

Vibration

Check the mounting for security and general conditions. With the inverter operating, listen for unusual noise or roughness. Roughness of the inverter may also be determined by placing your hand on the unit and feeling the vibration. If faulty, repair or replace inverter.

Sliprings and Commutators

Check sliprings and commutators for signs of arcing, burning, pitting, high or low segments, irregular surface, grooving, nonuniformity of surface, and wear. If feasible, the appearance of the sliprings and commutators should be observed at rest and while rotating. If faulty, repair or replace the inverter.

Cleanliness

Check the inverter for grease, oil, dirt and foreign material. Clean with a lint-free cloth, dry or slightly moistened with an approved solvent, or with dry compressed air.

Overheating

Check for signs of overheating. If necessary, repair or replace the inverter.

When performing a bench check include the following checks:

1. Carbon piles and related parts for chipping, arcing, burning, pitting, and breakage.
2. Voltage regulator for security of mounting and satisfactory operation.
3. Speed governor controls and all related parts for wear, bends, cracks, and burning.
4. All open type contact points for signs of arcing, pitting, and burning. Hermetically sealed units for proper operation.
5. Inverters for freedom of movement of the armatures.
6. Condition and operation of relays.
7. Receptacles and plugs for stripped threads or dents.
8. Wires for faulty insulation, deterioration, and chafing.
9. For noisy or rough bearings.
10. All moving parts. Repair or replace defective or worn parts.

In cases of failure or improper operation, inverters should be checked and serviced in accordance with the information given in their respective manuals. Some of these manuals contain troubleshooting charts which give the trouble, probable cause, and remedy. These are valuable in providing help in locating trouble.

Numerous failures and troubles may be due to conditions external to the inverter. Make sure all associated controls are in the proper positions and operating correctly. Check the fuses or circuit breakers of the connected circuits. Measure the d-c voltage to make sure proper

operating voltage is available for the inverter. Check the a-c output voltage at the inverter to make sure the cause of improper operation is not due to circuit failures or short circuits in connected loads.

INVERTER ADJUSTMENT

An important part of inverter maintenance is proper adjustment. Unless the inverter is properly adjusted it will not produce the desired output. The adjustment procedures for a particular inverter may be found in the applicable manuals on the inverter or on the test stand used.

For the purpose of illustration, the adjustment procedures for the familiar Navy type E-1617-1 (fig. 8-11) inverter are given. In many instances the test equipment listed in the manuals of the inverter are not available. When this is the case, the test equipment shown in figure 7-13 and 7-14, which is standard in Navy electric shops, may be used in adjusting inverters. In some cases the test equipment must be modified and also the procedures contained in the inverter's manual must be changed. The procedure given is that which should be used when using the drive stand and test assembly shown in the reference figures. The procedures that are given for adjusting the E-1617-1 inverter are generally applicable to most other inverters.

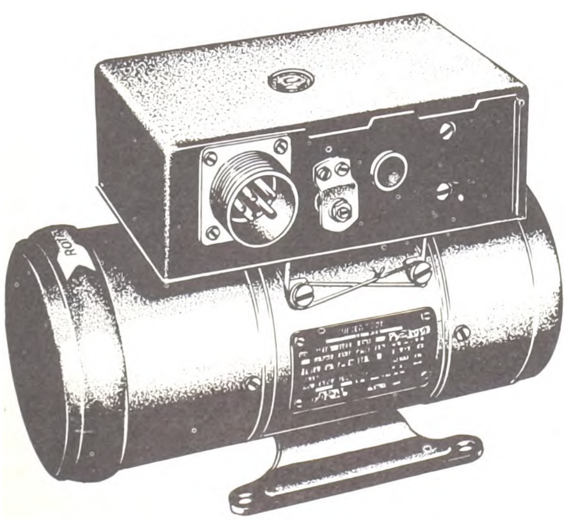


Figure 8-11.—Type E-1617-1 inverter.

The following limitations must be considered when using this test assembly for adjusting the E-1617-1 inverter. The lowest ranges of the ammeter and wattmeter in the test assembly are not low enough for the highest degree of accuracy when testing the inverter. Furthermore, the indicating meters of the test stand do present an appreciable load to the inverter. However, most of the tests can be made with all but the voltmeter and ammeter removed from the circuit. The short time needed to make a test requiring all meters in the circuit will not be injurious to the inverter.

Perform a phase sequence test before placing a load on the inverter otherwise the 3-phase wattmeter may be damaged. This may be done by observing the lamps on the phase sequence indicator. Lamp 1-2-3 should light for correct phase sequence. If lamp 3-2-1 lights, reverse any two leads at T1, T2, or T3 terminals.

The phase sequence of the E-1617-1 inverter is ACB. The test assembly is wired so that a lead from the single-phase wattmeter is tied to terminal T1 when the links on the test assembly are properly placed for 115-volts, 3-phase, 3-wire equipment, and the load disconnect is closed. Connecting the grounded phase (B of E-1617-1) of the equipment to terminal T1 of the test assembly will prevent energizing the potential coil of the single-phase wattmeter when testing 3-phase equipment that has one phase grounded.

In the test assembly, the maximum resistance available for loading one leg of an inverter is 158.6 ohms. Thus,

$$115 \text{ volts x } \frac{\sqrt{3}}{158.6} \text{ ohms} = 1.25$$

amperes line current.

Also,

$$1.25 \text{ amperes x } 115 \text{ volts x} \sqrt{3} = 250$$
volt-amperes,

which is the full load rating of the inverter; however, the power factors of the inverter and the load resistors are near unity. The rating of the E-1617-1 inverter is 250 volt-amperes. The 3-phase wattmeter and the frequency meters present an appreciable load to the inverter.

NOTE: It is normal for the wattmeter to indicate a reading with voltage applied but with no load current flowing.

The potential coil of the wattmeter is on the load side of its current coil. Thus, the wattmeter is indicating the current of its potential coil when voltage is applied. It is necessary to close the load-disconnect switch of the test assembly to energize the indicating meters. The 3-phase wattmeter will indicate approximately 50 watts when 3-phase, 115 volts is applied with the load switches open. Actually about 25 watts is the load presented to the inverter by the meters. In these tests, the wattmeter will be removed from the circuits in order to reduce this meter load.

CAUTION: Be sure 115-volt, 60-cycle power is applied to the fans of the test assembly; then, turn the ammeter-wattmeter switch to X10 range, then back to the X1 range. If the 115-volt, 60-cycle power is interrupted at any time, this selector switch must be recycled. There is an interlock which shorts out the secondary of the current transformers until the 60-cycle power is applied to the test assembly cooling fans, and the ammeter-wattmeter selector switch has been in the highest range. However, the shorting relay is not always effective. As a result, some current may be indicated before the selector switch has been cycled.

The procedure to be followed when testing and adjusting the inverter is as follows:

1. Mount a d-c generator (50 amperes or larger) on the generator drive stand. Connect the generator's positive terminal to B of the test assembly, the generator's negative terminal to -50, and the generator field to terminal A. Mount a good carbon-pile regulator on the pad provided on the test assembly. Adjust the voltage regulator rheostat to regulate the generator at 27.5 volts. Secure the generator drive stand before proceeding with the next step.
2. Clamp the inverter to the shelf of the test assembly. Remove the control box cover assembly.
3. Make a test harness to connect the inverter to the test assembly as shown in figure 8-12 (A).
4. Position the controls of the test assembly as follows:

CONTROL	POSITION
Connecting links	115-volt, 3-phase, 3-wire
Circuit selector switch	115-volt, 3-phase, 3-wire
D-c load switches	OFF
D-c voltmeter circuit selector	Inverter input
A-c	
A-c generator load switches	OFF
A-c voltmeter switch	T1-T2
T1, T2, T3 variable load switches	OFF
Load disconnect switch	ON
Frequency meter switches	High
Phase sequence indicator	High
Ammeter-wattmeter switch	Range X1
T1, T2, T3 variable loads	Fully counter-clockwise
Regulator-rheostat switch	Regulator
D-c ammeter selector switch	X1
Inverter input switch	OFF
Fan switch	ON
Ammeter-wattmeter selector switch X10 position, then to X1 position	

NOTE: 1. Remove the three links, located just above the two wattmeter fuses, marked T1, N, and T3. (Labels are under links.) By removing these links, the wattmeter is removed from the circuits. 2. Remove the shorting bar from the relay mounting pad. (Terminals GEN and BAT.) When starting the inverter, turn the d-c ammeter selector switch to the X5 position, then start the inverter; return the switch to the X1 position as soon as the inverter is started to

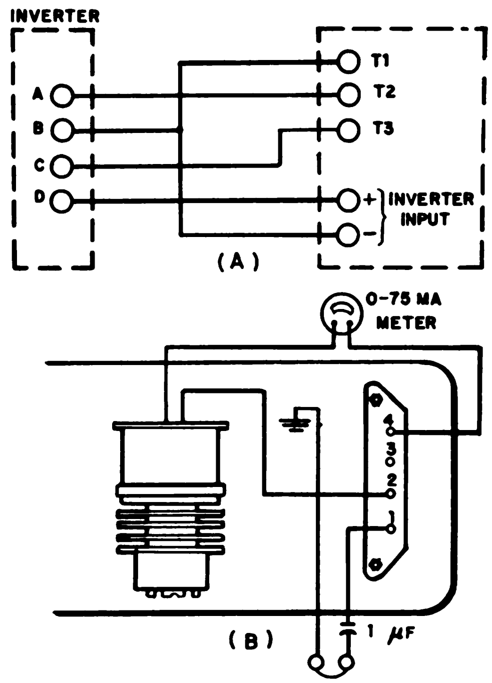


Figure 8-12.—(A) Inverter connections to test assembly; (B) earphone and milliammeter connections.

prevent inverter starting current from damaging the ammeter.

5. Start the d-c generator and set the regulated voltage to 27.5 volts.

6. Start the inverter. Phase sequence indicator light 1-2-3 should glow to indicate proper phase sequence of inverter. If the inverter output has wrong phase sequence, return the inverter to be overhauled.

7. Check d-c input current to inverter. The d-c input current should be about 12 amperes with no load on inverter. Excessive input current indicates defective motor or bearings.

8. Bench check the inverter according to the directions given in the previous section of this chapter.

9. Milliammeter connections: Remove the wire from terminal 4 of the inverter terminal board which comes out of the rear of the carbon pile, and connect it to the positive lead of a 0-75 milliampere d-c meter. Connect the negative lead of the milliammeter to terminal 4 of the terminal board. (See fig. 8-12 (B).) Make certain that the milliammeter connections are good. An open in the carbon-pile circuit will cause excessively high inverter output voltage.

10. Earphone connections: Connect one lead of the earphones to the ground screw; connect a 1-microfarad capacitor in series with the other earphone lead to terminal No. 1 of the inverter terminal board. Earphones are worn by the operator during the test and adjustment procedure in order to listen to the operation of the voltage regulator. A steady humming noise in the earphones indicates that the voltage regulator is stable. A rapid series of staccato noises indicates instability in regulator operation. When the pile adjusting screw is too loose, the armature vibrates rapidly. This action is termed instability and results in arcing between the disks of the carbon pile and/or the carbon contact plugs. It is important that the voltage regulator never be operated in an unstable condition since the arcing causes burning and pitting of carbon disks and contact plugs, thus preventing proper regulation of the output voltage. If the voltage regulator becomes unstable during the test and adjustment procedure, immediately turn the pile adjusting screw in a clockwise direction until instability disappears. The single thud heard in the earphones each time the inverter load is changed should not be confused with instability; this will occur with a stable regulator.

11. Frequency checks: Start the inverter and observe the frequency meters. With a 27.5-volt d-c input to the inverter, the output frequency of the inverter should remain between 390 and 410 cycles per second from no load to the full load on the inverter. To load the inverter, close T1, T2, and T3 inverter load switches. Make certain the three variable load resistor knobs are fully counterclockwise. Closing these load switches puts approximately 10 percent overload on the inverter (load resistors plus load of meters). With load switches closed, check the current in each of the 3 phases of the inverter. The current should be about 1.25 amperes and equal on all 3 phases. Check the voltage on phases T1-T2, T1-T3, and T2-T3. If voltages are not within 5 volts of each other and currents are unequal by a corresponding percentage, return the inverter to be overhauled. If voltages are equal and currents unequal by more than 5 percent, check the test assembly for improper setting or possible defect.

CAUTION: Do not leave the load switches closed for more than 10 minutes at one time; followed by a 10-minute running of the inverter

at no load to prevent overheating. Output frequency is one element establishing output voltage. Output frequency is checked and corrected, if necessary, before setting the voltage regulator. Make certain that the voltage does not increase beyond 115 volts during the frequency check. The cover at the d-c end of the inverter should remain on to provide proper cooling of the inverter.

12. Governor adjustment: The setting of the governor contact springs is factory adjusted and should not be disturbed. If improper speed control results from tampering with or damage to the governor, replace the fan with a new assembly. When a new assembly is not available, the governor contact springs may be set in accordance with the directions given in the Overhaul and Service Instructions.

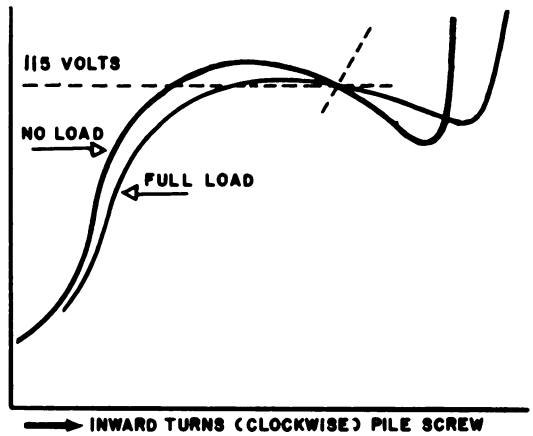


Figure 8-13.—Carbon-pile characteristic curve for E-1617-1 inverter.

13. Adjustment of the carbon-pile regulator:

a. Loosen the locking nut and turn the voltage-adjusting rheostat until its contact arm is in midposition.

b. Remove the link T1, located just below the frequency meter. This removes the frequency meter from the circuit.

c. Using earphones, check the inverter for stability.

d. Turn the carbon-pile adjusting screw out (counterclockwise) about one-half turn or until the output voltage has dropped to about 80 volts. Then, slowly turn the pile screw inward (clockwise) and note the voltage across the controlled phase AB(T1-T2). The voltage must rise to a maximum and then decrease. Turn the pile screw in until the voltage has decreased about 10 volts from the maximum. This is approximately the proper adjustment point. Apply full load to the inverter. (Close inverter load switches T1, T2, and T3.) Note the full load voltage. The carbon-pile characteristic curve is shown in figure 8-13. The proper adjustment point for the carbon pile is the point where the no load and full load voltages across the regulated phase are exactly equal. If this voltage is not 115 volts, loosen the core-locking screws and turn the magnet core until the regulated voltage is 115 volts. Now recheck the no load and full load regulated voltages to be sure that the proper positions of the pile screw and the core screw have been established. During the pile and core screw adjustment, listen on the earphones for instability of the carbon pile. Check the stability by switching the load on and off several times. If the regulator is unstable, return the inverter to overhaul.

e. Check the coil current, as read on the d-c milliameter. With the potentiometer set at midposition and the regulator adjusted properly, the coil current should fall within the range of 56 to 64 milliamperes. If it is outside of this range, return the inverter to be overhauled. When coil current is outside the given range, voltage regulation by the carbon-pile regulator is faulty.

f. When proper voltage is reached, tighten the core-locking screws. Tightening the locking screws may change the voltage slightly. To compensate for this effect, a slight modification of the setting must be made beforehand to allow for the change caused by tightening the locking screws. Recheck for stability.

14. Heat run: After the inverter has been running at least 30 minutes to reach operating temperature, check output voltages, input current, and frequency (replace the link to energize meters) with the values in table 8-1. All readings should be within the limits given. Recheck for stability and adjust the carbon-pile regulator as before, if necessary, to give the required voltage value when the inverter is operating under hot conditions. The carbon-pile setting that is required is one that provides 115 volts ± 5 volts under both initial starting and normal operating temperature. Changes to the voltage regulator setting should not be made, however, following the heat setting. If proper regulation cannot be obtained, return the inverter to overhaul.

Table 8-1.—E-1617-1 inverter test ratings.

Three-phase load

D-c input		A-c output		Coil current (milliamps)	Load 3-phase balanced
Volts	Amps (max)	Volts (line to line)	Amps (max)		
29	12	115 ± 5	1.25	56 to 64	No load
29	22	115 ± 5		56 to 64	Full load
27.5	12.7	115 ± 5		56 to 64	No load
27.5	23.5	115 ± 5	1.25	56 to 64	Full load
26	13.5	115 ± 5		56 to 64	No load
26	25	115 ± 5	1.25	56 to 64	Full load

Single-phase load [1]

D-c input		A-c output phase AB		Coil current (milliamps)	Load phase AB
Volts	Amps (max)	Volts (A to B)	Amps (line A or B)		
29	12	115 + 5		56 to 64	No load
29	22	115 + 5, -10	2.17	56 to 64	Full load
27.5	12.7	115 + 5		56 to 64	No load
27.5	23.5	115 + 5, -10	2.17	56 to 64	Full load
26	13.5	115 + 5		56 to 64	No load
26	25	115 + 5, -10	2.17	56 to 64	Full load

[1] To apply a single-phase load to the inverter, close load switch T2 and adjust variable load knobs for 2.17 amperes. Be certain that the voltmeter selector switch is on T1 - T2 position and that the ammeter selector switch is on phase 1.

When a single-phase load is applied to the inverter, a considerable amount of the third-harmonic of the fundamental appears in the waveform. The voltmeter may show nearly 10 volts drop with load as the single-phase load is applied to a good inverter.

The output frequency should remain between 390 to 410 cycles per second during these checks.

TYPICAL A-C POWER SYSTEM

This typical system is given for the purpose of acquainting you with the components of a system and to show how these various components are interconnected. Refer to figure 8-14 when studying this system. The following items should be noted:

1. The main inverter start relay is part of the main inverter assembly.
2. When the inverter transfer switch is placed in STDBY, both the standby inverter start relay and the inverter transfer relay are energized.
3. The center position of the switch is OFF.
4. With the inverter transfer switch in the MAIN position, standby inverter power is supplied to the IFF radar receiver-transmitter by turning on the IFF radar control unit, which energizes the standby inverter start relay.

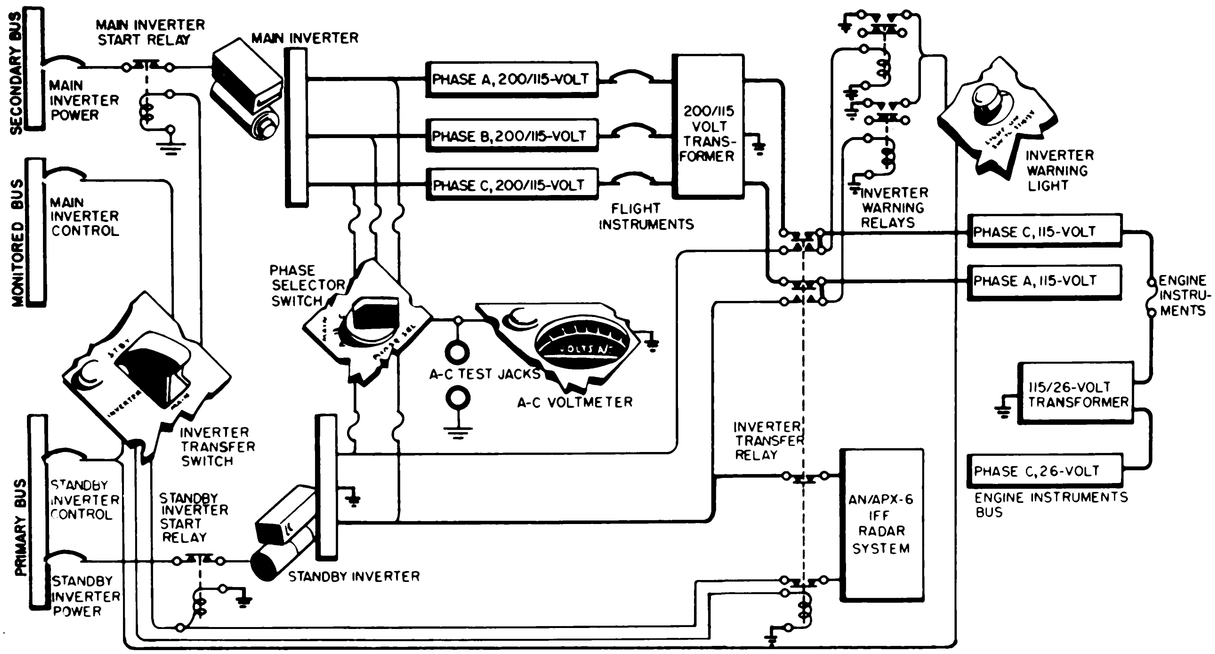


Figure 8-14.—A-c power supply and distribution system.

5. When either inverter warning relay coil is energized by less than 75 volts, the relay connects the warning light to ground.

The a-c power requirements of a typical aircraft system are furnished by a main inverter and a standby inverter. The two inverters are energized by the aircraft's d-c power system. Both inverters are used during normal operation.

NORMAL OPERATION

An inverter transfer switch is used to select one of the two inverters. The center position of the switch is OFF. In MAIN, the switch connects d-c power from the monitored bus to the coil of a built-in start relay in the main inverter, which then connects d-c power from the secondary bus to the main inverter. Three-phase, 115/200-volt, 400-cps a-c power is then delivered by the inverter to the buses. A 115/200-volt transformer, which is protected by flight instrument circuit breakers, reduces the voltage to 2-phase, 115-volt power. This power is then connected through a deenergized inverter transfer relay to the two flight instrument buses. A 115/26-volt transformer further reduces the voltage to single-phase, 26-volt power for the engine instrument bus.

Phase-to-ground output voltages of the inverter are indicated by an a-c voltmeter, with which a phase selector switch is used to select main and standby inverter phases for readings. The main inverter is protected by the main inverter control and the main inverter power circuit breakers.

The standby inverter is protected by a standby inverter power circuit breaker. Output voltages of the standby inverter are also indicated by the a-c voltmeter as selected by the phase selector switch. The standby inverter control circuit and the warning light circuit are protected by a standby inverter control circuit breaker.

Normal operation of the standby inverter is controlled by the IFF radar system. When the IFF radar set control unit is turned on, power is delivered through the deenergized inverter transfer relay to the coil of the standby inverter start relay, which connects starting power from the primary bus to the 115-volt, 400-cps, 3-phase standby inverter. Phase A voltage is then

connected through the deenergized inverter transfer relay to the IFF radar system.

EMERGENCY OPERATION

During normal operation of the main inverter, current from the 115-volt A and C phases energizes the coils of two inverter warning relays, which hold open an inverter warning light circuit. When the voltage of either of these phases drops below 75 volts, the corresponding warning relay connects the inverter warning light circuit to ground.

Placing the inverter transfer switch in STDBY disconnects power to the main inverter built-in start relay, energizes the inverter transfer relay, and connects power to the main inverter built-in start relay, energizes the inverter transfer relay, and connects power to the standby inverter start relay. The flight instrument and engine instrument buses are essential and are connected to the standby inverter when the transfer relay is energized.

The inverter transfer relay also disconnects the standby inverter from the IFF radar system and energizes the inverter warning relays, turning off the inverter warning light.

CHAPTER 9

AIRCRAFT STARTERS

An aircraft starter is a mechanism for developing a considerable amount of mechanical energy that can be applied to the engine to cause it to rotate. The starter must develop sufficient power and be dependable, light in weight, and simple to operate and maintain. Various types of starter accessory units—such as solenoid-operated meshing devices, solenoid-operated starting switches, control switches, and external energizers—are used in conjunction with starters to facilitate installation and improve operation.

The type of starter used for cranking reciprocating engines is the direct cranking electric starter. The starting of a turbojet or turboprop is somewhat different from reciprocating engine starting and is discussed later in this chapter.

RECIPROCATING ENGINE STARTER

DIRECT CRANKING ELECTRIC STARTER

The direct cranking electric starter is the most widely utilized starter on large aircraft engines at present. Figure 9-1 shows a typical direct cranking electric starter for reciprocating engines.

This starter contains a series-wound electric motor, speed reduction gears, an overload clutch, and an automatic engagement jaw. The torque developed in the motor is transmitted to the jaw through a gear reduction system. Because of the high-speed characteristics of the motor and lightweight structural design, the overall weight is reduced to a minimum and, at the same time, maximum cranking torque is maintained. The high speed of the motor is reduced by gear reduction between the motor armature and the low-speed starter jaw.

A torque limiting clutch incorporated in the housing prevents damage either to the starter or the engine when the moving starter jaw is engaged with the stationary engine jaw. The clutch plates will slip when the torque exceeds the clutch setting of the starter. As the torque decreases to a value less than the clutch setting, the clutch plates will again be held stationary and allow the jaw to rotate at the speed of the motor through the reduction gearing.

The starter jaw is automatically engaged with the engine jaw by means of a spiral spline actuating device. When the engine starts, the sloping ramps of the jaw teeth cause the disengagement of the starter and engine jaws. Oil seals are provided to prevent the leakage of engine oil into the starter.

OPERATING INSTRUCTIONS

Starting motors are of the intermittent-duty type. They must be allowed to cool between starting intervals in order to prevent overheating and possible damage. However, some starters are designed so that two starting cycles may be used before a cooling-off period is necessary. Consult the applicable manuals for specific information on the particular starter with which you are working.

When operating starters which utilize a flywheel, overspeeding must be avoided. When a power supply other than batteries is used, the higher voltage produces more rapid acceleration and, therefore, the energizing time must be reduced accordingly.

External power supplies (auxiliary power units) should always be used for starting aircraft engines. This is particularly true when using the direct cranking starter due to the high current drawn by this type unit.

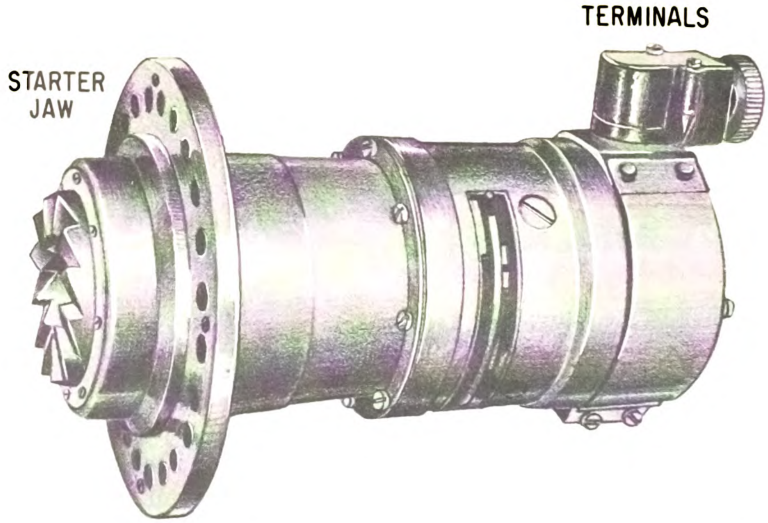


Figure 9-1.—Typical direct cranking electric starter.

JET ENGINE STARTERS

The starting of the gas turbine (jet) engine has been one of the major problems in the operation of turbojet and turboprop aircraft. Starting the piston powerplant of aircraft, on the other hand, is a relatively easy matter, since the engine is given a few turns after which it fires. After it once fires, there is usually no further need of the starter for that particular start. With the starting of the gas turbine engine, a powerful starter is required for initial firing, and it must continue to energize the engine until the engine is turning at a speed sufficient to maintain combustion on its own. Turbojets with turbine wheels of 3 feet or more in diameter must be turned at speeds of 3,000 to 5,000 rpm to sustain combustion in the engine. The starter must assist the engine until the engine rotor has reached about 20 to 30 percent rpm.

Regardless of the type of starting system used, it must be capable of starting the gas turbine in 20 to 30 seconds. It must be remembered that the secret of quick starting depends on the power developed by the starter. In order to start a gas turbine engine capable of 5,000 pounds of thrust in 20 seconds, a starter must produce 60 hp. To reduce starting time to 3 seconds, for instance, the starter must produce approximately 400 hp.

THEORY OF OPERATION

In a direct cranking jet electric starter, torque is transmitted by motor action through the reduction gear assembly and overload clutch assembly to the starter jaw. The jaw then moves forward, engages the engine jaw, and cranks the engine.

The construction of gas turbine engine electric starters is practically the same as that of reciprocating direct cranking starters. Basically, a typical jet electric starter consists of a motor, reduction gear assembly, clutch, and starter jaw shaft.

A common type motor is the compound motor with interpoles.

The reduction gear assembly (planetary assembly) is used to convert the high-speed, low-torque output of the motor into low speed, high torque to crank the engine. A typical gear ratio is 4:1. The gear unit, as a section, separates from the motor easily during overhaul.

The clutch housing encloses a multiple disk clutch (clutch pack). The disk plates are alternately steel and bronze with no lubrication between them. This is known as a dry pack. The disk clutch is a torque limiting device designed to protect the starter and engine mechanism against overload. The friction between disks can be regulated by means of the clutch adjusting nut to set up a specific torque limit which is determined by the maximum allowable output

of the starter and the engine cranking torque requirement. When the torque on the starter exceeds the clutch setting, the clutch will slip and the starter will not assume the added load.

The starter jaw shaft, similar to the Bendix drive of an automobile starter, is a screw with left-hand threads, that holds the starter jaw. As the starter rotates clockwise, the screw rotates and moves forward (principle of a screwjack). A jaw return spring aids in returning the screw shaft to its retracted position at the appropriate time. For a starter that rotates counterclockwise, the screw shaft will have right-hand threads.

TYPICAL JET ELECTRIC STARTING SYSTEM

Figure 9-2 is the schematic drawing of a typical jet electric starting control circuit.

For ground starts, an external power supply must be used with this system. For air starts, the windmilling of the engine is sufficient and the starter is not used. For starting, the engine start master switch must be placed in the START (closed) position, and the engine crank switch must be momentarily set to the CRANK (closed) position. This actuates the starter relay of the starter undercurrent (dropout) relay unit. The closing of this relay connects power from the fuel control circuit to the small prong of the starting external power receptacle. This actuates a relay within the external power unit which, in turn, supplies power from the external power unit to the large prongs of the starting external power receptacle.

At the time the aircraft bus is actuating the relay within the external power unit, it also actuates the starter relay of the starter undercurrent relay unit. This relay shunts current from the positve terminal of the starting external power receptacle through the sparsely wound actuating coil of the automatic cutout relay (within the starter undercurrent relay unit), and

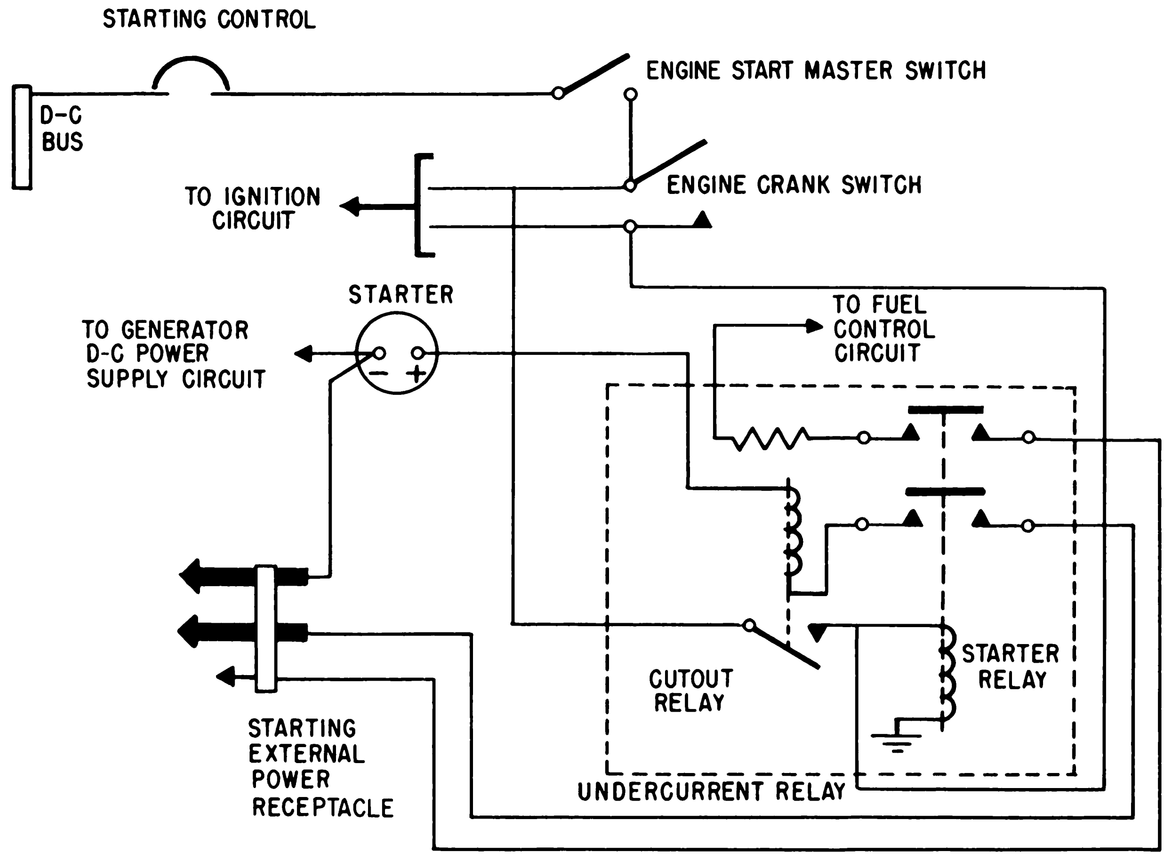


Figure 9-2.—Jet starting control circuit.

then to the starter. The starter current actuates and holds the automatic cutout relay closed. As the aircraft starter motor increases in speed, its back emf increases and consequently the current demand is lessened. When the starter current decreases to 235 amperes ± 15 amperes, the undercurrent (cutout) relay in the aircraft drops out. This breaks the starter relay holding circuit, thus deenergizing the starter relay which, in turn, disconnects the external jet starting generator from the aircraft starter motor.

Actuation of the automatic cutout relay creates a holding circuit for the starter current relay (within the starter undercurrent relay unit) by supplying power to its actuating coil from the aircraft bus, available through the engine starting master switch. When the starter has reached the speed which permits the automatic cutout relay to open, the current to the starter current relay will also open and cut off the starter.

Auxiliary power units, such as the NC-5, used for starting jet aircraft engines using electric starters, incorporate features which provide a "soft start." This prevents sudden mechanical shock and inrush currents to the aircraft starter prior to and during the time the starter dog engages with the engine. The NC-5 accomplishes this by lowering its output voltage to below 6 volts at the beginning of the starting cycle. While this low voltage is maintained, the jet starting contactor closes and delivers current to the aircraft starter. After a current of approximately 100 amperes is reached, the starter dog engages with a minimum of force. Now the voltage output of the auxiliary power unit is allowed to start rising toward 35 volts, and the current is limited to a value between 1,000 and 1,100 amperes.

Another type of electric starter is the combination starter-generator. This unit serves the dual function of starting the engine through motor action and of supplying the aircraft with electrical power through generator action. This unit is coupled directly to the engine through a splined stub shaft and does not incorporate gearing, a slip clutch, or an engaging jaw. Figure 9-3 illustrates schematically this type starter system.

When the engine master switch is closed to energize the control circuits and the momentary start-stop switch is pressed to energize the starter relay coil, the starter relay is closed. This allows current from the aircraft bus to flow to the external power supply via the small pin in the engine starter receptacle. The action that follows is similar to that just described in connection with a conventional jet electric starter.

When the contacts of the undercurrent relay open (fig. 9-3), both the starter relay and the starter shunt-field control relay are deenergized. The opening of the starter relay disconnects the starter field from the external power supply, and the opening of the starter shunt-field control relay removes the short circuit that was across the voltage regulator during starting. The automatic starting circuit can be deenergized by momentarily depressing the STOP switch. This deenergizes the starter-controller relay and disconnects power to the starter-generator.

As the aircraft engine speed is increased, the starter-generator begins to supply the primary power for the electrical system of the aircraft.

PNEUMATIC JET ENGINE STARTER

The development of increasingly large gas turbine engines has created a need for high horsepower starting systems beyond the practical application of electric motors. The gas turbine pneumatic starting system has been developed to fill this need.

This type engine starting system utilizes compressed air to rotate the engine. Rotation of the engine for ground starts is accomplished by the air-turbine starter which is powered by compressed air derived from an external compressor assembly. A typical pneumatic starter unit is shown in figure 9-4.

Figure 9-5 is the electrical schematic of a typical pneumatic starter system. Compressed air enters the starter when the shutoff valve on the compressor is energized. The starter control switches provide cockpit control of the starting system. When the power switch is closed, depressing the start button completes a circuit from the d-c source through the starter centrifugal switch to the shutoff valve. The valve, in turn, opens the compressed air outlet to the starter which rotates the engine until the specified maximum starting rpm (starter cutout speed) is attained.

The holding relay keeps the valve energized after the start button is released. When the correct rpm is reached, the starter centrifugal switch opens the power circuit and the shutoff valve acts to shut off the air supply from the compressor to the starter. When this switch opens, the holding relay is deenergized. This

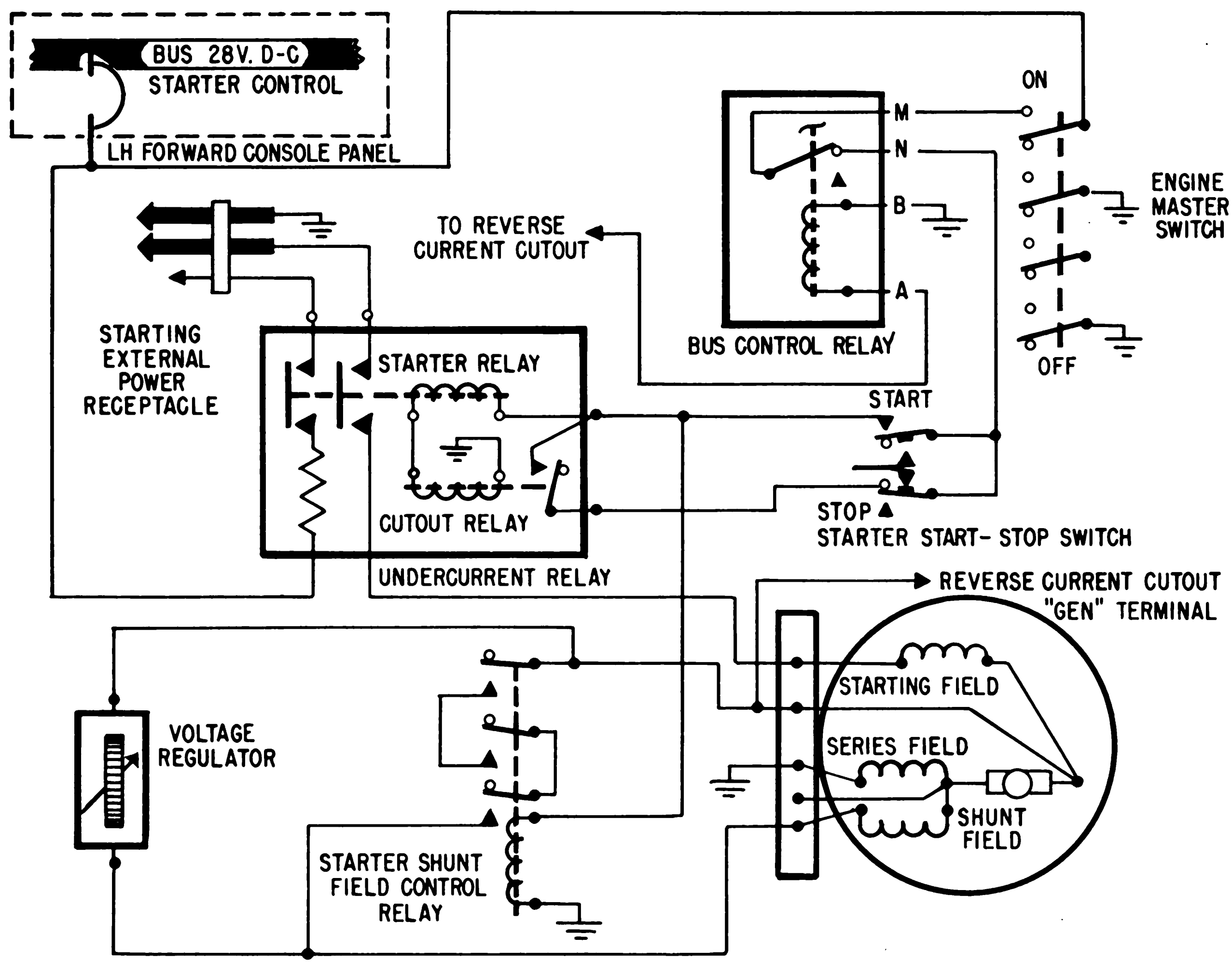


Figure 9-3.—Combination starter-generator system.

prevents the starting cycle from automatically recurring when the rpm of the engine drops off to the point that the centrifugal switch closes. If for any reason a faulty start occurs, the starting cycle can be terminated by manually opening the starter power switch.

Portable Probe Starter

Another type of pneumatic starter is the portable probe starter. This is a starter that is mounted externally on the aircraft only during starting periods. This portable starter consists primarily of a geared drive shaft (probe). The shaft is driven by a separate portable air turbine unit. These gas turbine compressor air supply units may be mounted in trailers, on tow tractors, or be constructed as a pod unit. The pod type unit is shown in figure 9-6.

A starter probe is designed for a particular model aircraft; however, the turbine drive unit may be used to drive different type probes, or other type starter systems. Presently the A-4A and F-8C aircraft use the probe application of this type pneumatic starter. An advantage of the probe starter is that the aircraft is not equipped

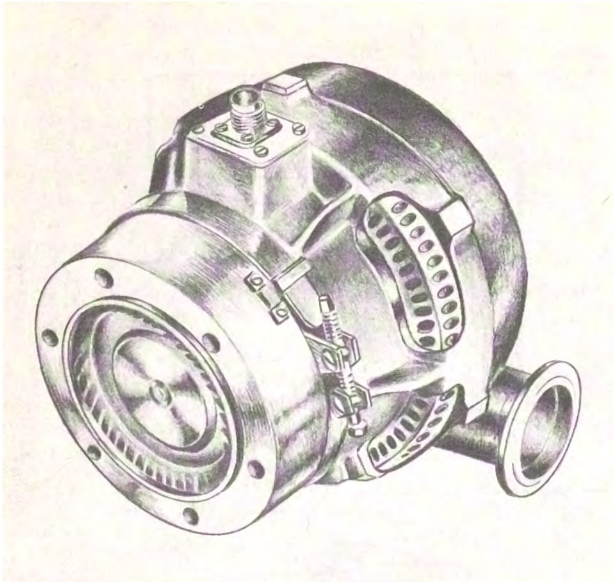


Figure 9-4.—Pneumatic starter.

with a permanently mounted starter; thus a reduction in overall aircraft weight is afforded.

The starter probe is used to rotate the engine compressor to accomplish ground starts of the aircraft engine. In a typical installation, the probe is inserted through an opening in the lower part of the fuselage. The upper end of the drive shaft contains a spring-loaded ratchet gear which engages the starter gear on the generator drive transmission. The external starter compressor (air turbine) supplies compressed air to the air turbine starter, which drives a high-speed turbine wheel with low-torque output. The output is transformed by reduction gears in the starter turbine unit housing to a low-speed, high-torque output which rotates the probe drive shaft. A sleeve on top of the starter probe housing encases the lower end of the drive shaft and contains a lever-operated electrical contact. When the starter probe is installed in the starting position on the aircraft, movement of the lever to the DOWN position simultaneously accomplishes two functions—(1) it locks the starter probe in position, and (2) it completes the electrical circuit from the ground start switch in the cockpit, through the speed sensing switch, to an electrical receptacle on the starter probe housing. Under these conditions the aircraft engine should start; after the engine has started, the lever is returned to its UP position and the probe is removed. The probe unit is equipped with heat-resistant handles and rubber wheels to facilitate ground handling.

Because the portable probe starters have created undesirable logistic problems, they are being phased out of future Navy aircraft design. They are being replaced by conventional engine-mounted starters.

Turbine Impingement Starting

On modern naval aircraft such as the F-4B the jet engines are started by means of low-pressure air directed onto the second-stage turbine rotor buckets (turbine impingement starting). (See fig. 9-7.) Impingement starting may be accomplished by directing jets of compressed air into blades in either the compressor or turbine section of a gas turbine engine. The number of air outlets and air pressure required for impingement starts vary as the size, weight, and design parameters of the engine to be started vary. The impingement type starting discussed in this chapter is the starting system of the F-4B aircraft and is not the impingement starting system used by all manufacturers. This is included here for illustration purposes.

Starting air is supplied by an external starting unit and is controlled by an air shutoff valve in the external air supply unit. The shutoff valve is electrically controlled by the applicable engine starter switch through the start relay. The starting air is delivered through a flexible hose to the starting manifold connection. The air is

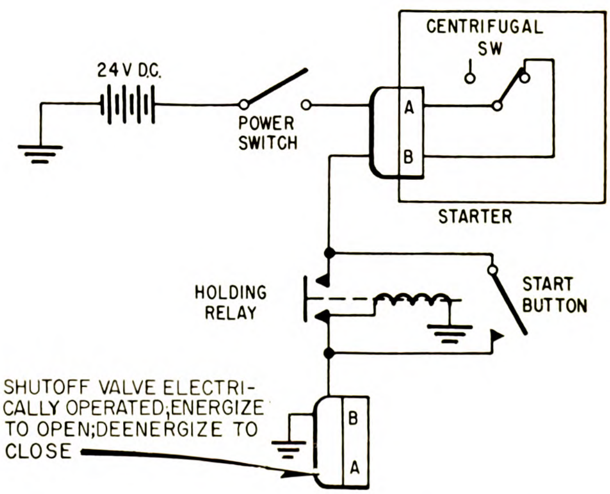


Figure 9-5.—Electrical schematic of a typical pneumatic starter.

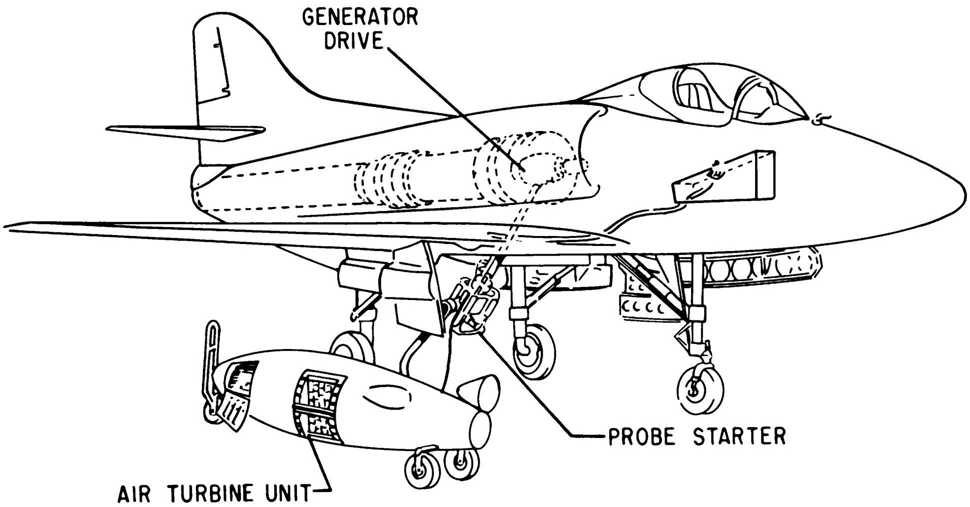


Figure 9-6.—Portable probe starting.

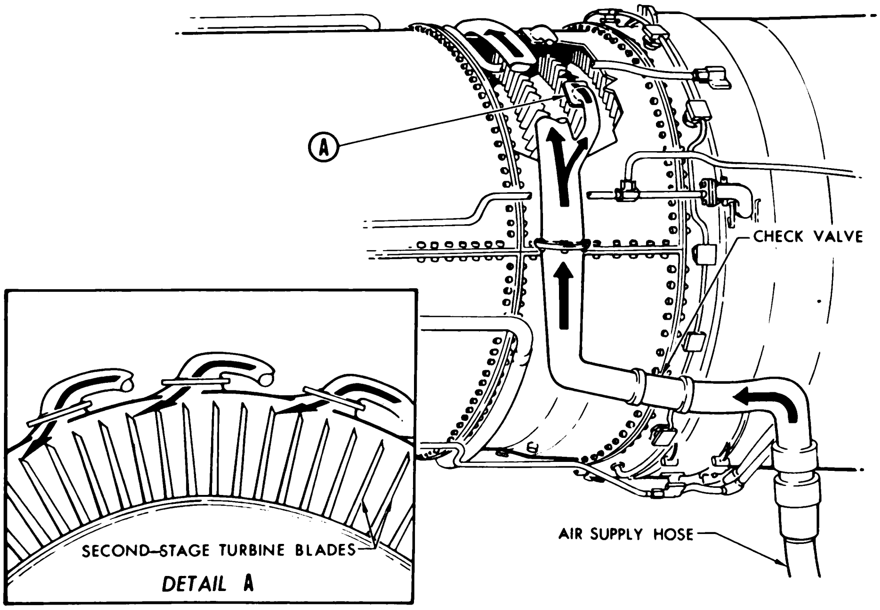


Figure 9-7.—Turbine impingement starting.

then ducted through the impingement manifold and directed onto the second-stage turbine buckets at seven points at the top of the turbine casing.

A check valve in the starting manifold prevents loss of gases after the engine is started. The external starting unit electrical connector must be plugged into the receptacle corresponding to the engine being started. In addition to the air supply, external electrical power must be applied to the aircraft before the engines can be started. The function of the turbine impingement starting system is to start and sustain engine rotation at a speed at which the fuel-air mixture

is satisfactory for light-off, and also to assist the engine to increase rpm until it is self-sustaining.

For operation of the system, an external power source and an external air supply with its air valve control circuit must be applied to the aircraft. Air from the external source is conducted to the quick-disconnect fitting and from there to the left or right selector valve. These valves will distribute air to either the left or right engine, depending upon the position of the cockpit selector switch (fig. 9-8). The engine manifold assembly distributes the starting air to seven impingement nozzles, which directs the air against the second-stage turbine blades of the engine turbine wheel.

The impingement starting system flow schematic is shown in figure 9-8. With the cockpit switch in the left engine start position, the energized solenoid on the left selector valve plunger positions the free floating ball to allow the inner cylinder to vent to the downstream side of the selector valve. Air pressure cannot move the piston against the piston spring because of a greater area on the lower portion of the exposed piston face. With the solenoid energized, the inside of the selector valve piston becomes evacuated and the starting air supply will act on the outside of the piston causing the piston to move to the open position, thereby permitting an air supply to move toward the left engine nozzles. With the right solenoid deenergized, air pressure flows past the free floating ball into the inner cylinder. The air pressure is equalized on both sides of the piston and the valve remains closed. (NOTE: With the cockpit switch in the OFF position, both valves will remain closed. Therefore, even with starting air and electrical power supplied, neither engine will start until the cockpit switch is in the left or right position.)

Both in air turbine starting and turbine impingement starting, an external gas turbine compressor is used for the air source to supply air for turning over the engine for starting. These units have different air supply requirements; therefore, when starting an engine with turbine impingement starting, make sure a gas turbine compressor with a suitable high airflow rating is used. Prior to starting a jet engine, the recommended airflow requirements in the applicable Maintenance Instructions Manual should be consulted.

INSPECTION AND MAINTENANCE

The details of inspection and maintenance will vary somewhat with different starter types and makes, but the following procedures will generally prove satisfactory. For detailed instructions consult the applicable manuals that are provided for the aircraft or component.

INSPECTIONS

Although the inspection of aircraft starters will vary with the type of aircraft, the basic checks mentioned in the following paragraphs can be used as a guide. The AE should give the unit a thorough visual inspection for housing failures or cracks, especially at the mounting head and jaw. Inspect the mounting head to see that it is securely bolted and not damaged. Check all safety wiring and electrical and mechanical connections for tightness.

When inspecting electrical starters, the following procedures are recommended. Remove the window strap from the starter. Carefully examine the underside of the strap for presence of oil, and particles of copper, solder, carbon, insulation, or other foreign matter. Absence of such matter usually indicates that the motor is in satisfactory operating condition. Presence of foreign matter is an indication of faulty parts in the starter, in which case it will be necessary to remove the starter from the engine and return it to a qualified overhaul base.

Check jaw meshing solenoids for satisfactory operation. If the starter is sluggish, and the battery or wiring is not at fault, replace the solenoid or the complete starter if the solenoid is an integral part of the starter. (NOTE: The procedures for checking and maintaining brushes, commutators, connections, and wiring on starters are very similar to the procedures used with generators. This information was presented in chapter 7.)

When inspecting integral mounted pneumatic starters, check to insure that all air ducts are secure. All inlet areas must be checked for presence of foreign matter. The starter should be checked for physical condition and secure mounting. The condition of the electrical wiring should be inspected visually for evidence of worn or frayed insulation and any corrosion. Inspect all terminals and receptacles for evidence of burned or damaged contact pins. External threads must be free of damage that would prevent the mating connector from being securely attached.

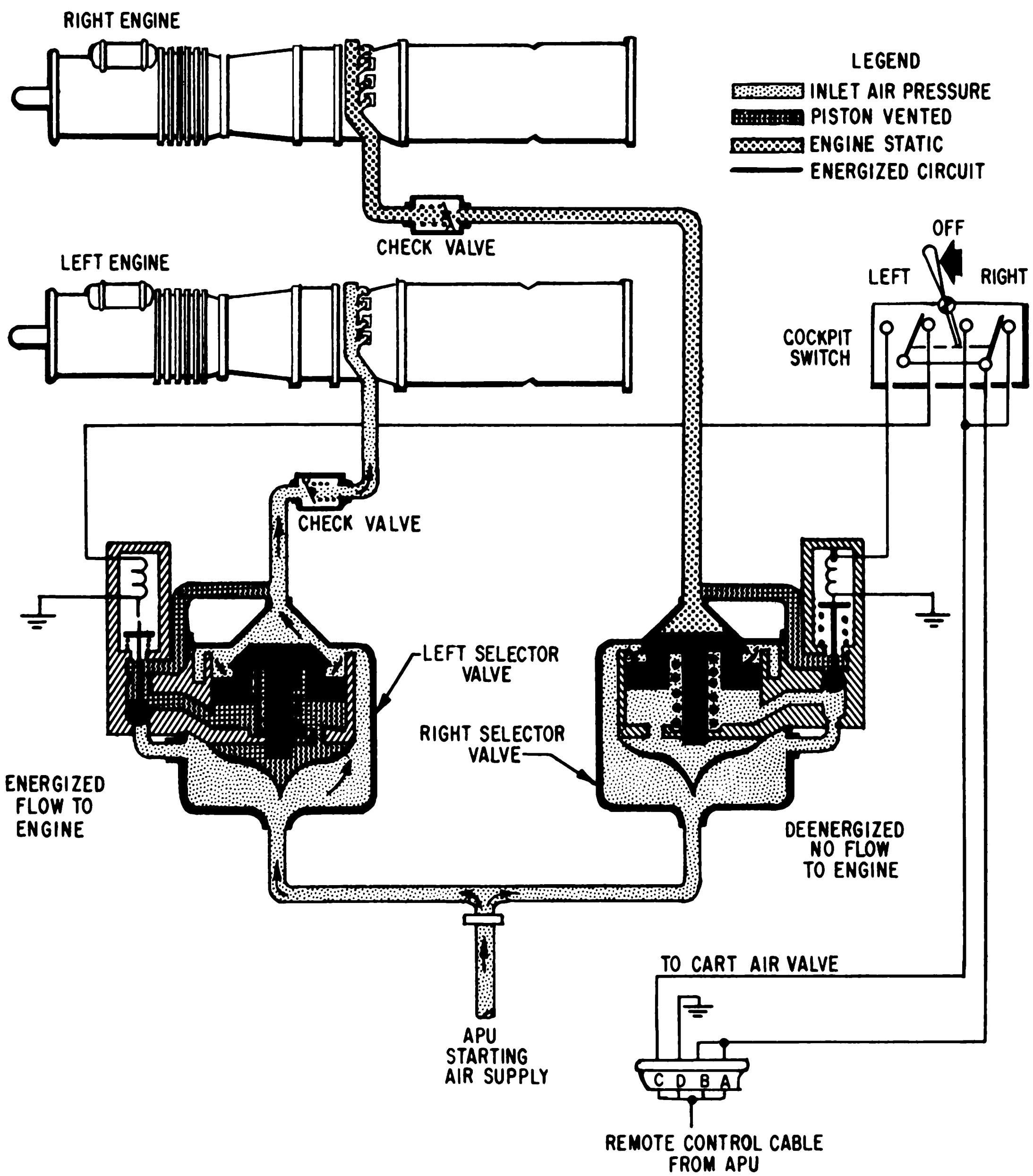


Figure 9-8.—Impingement starting system flow schematic.

The portable probe type pneumatic starter inspections are the same as the integral mounted pneumatic starter with the following exceptions:

1. Particular attention must be given to the servicing of the starter motor and starter gearbox.

2. Proper lubrication of the drive unit, the shaft universal joint, and the spline should be performed before each start or starting attempt.

When inspecting air impingement starting systems, check to insure that all air inlet ducts are secure. All inlet and exhaust areas must be checked for presence of foreign objects. Operation of all electrical solenoids and selector valves are paramount for trouble-free service. Switches, solenoids, valves, and all electrical leads should be checked thoroughly for corrosion, worn, frayed, or broken insulation.

Table 9-1.—Troubleshooting chart.

Trouble	Probable cause	Remedy
Starter operates but fails to crank engine.	Leakage of engine oil into starter.	Forward for overhaul.
	Clutch not properly set.	Forward for overhaul.
	Return jaw does not advance into engagement.	Forward for overhaul.
	Sheared output shaft.	Forward for overhaul.
Starter fails to operate or operates at too low a speed.	Low voltage caused by defective or incorrect power supply.	Check power supply; check line voltage during starting cycle.
	Loose, dirty, or improper external electrical connections.	Tighten, clean and check connections against wiring diagram.
	Binding brushes	Service the brushes.
	Dirty commutator	Clean the commutator.
	High commutator bars	Forward for overhaul.
	Rough, pitted, or scored commutator	Forward for overhaul.
	Damaged internal wiring connections	Forward for overhaul.
	Worn, broken, or improperly lubricated ball bearings.	Forward for overhaul.
	Dirty or pitted relay contacts	Clean contacts or replace relay.
Excessive wear and arcing of brushes.	Binding, worn, or improperly seated brushes.	Service brushes.
	Dirty commutator	Clean commutator.
	Brush spring tension incorrect	Forward for overhaul.
	Worn motor bearing	Forward for overhaul.
	Rough, pitted, or scored commutator	Forward for overhaul.

The AE should consult the applicable Maintenance Instructions Manual for the proper inspection procedure for the individual type starter.

TESTING

The electrical testing of armatures and field windings is very similar to that of generators. Refer to chapter 7 of this course for the correct procedures for testing armatures and field windings. Mechanical testing is performed on a starter test stand in accordance with the manufacturer's specifications. This test generally consists of measurements for clutch slipping torque, jaw speed, starting current, and running current for electrical type starters. Testing of pneumatic types includes stall airflow, overspeed, functional air leakage, no load, and overrunning tests. Mechanical testing of all types of starters is usually performed by the overhaul and repair activity.

TROUBLESHOOTING

Maintenance Instructions Manuals usually contain troubleshooting charts or tables to aid the AE in locating and eliminating starter troubles quickly. Before attempting troubleshooting, consult the applicable manual for detailed instructions. Table 9-1 is an example of a typical troubleshooting chart for the direct crank electric starter.

Before installing a starter, check the data plate to make certain that the starter is the proper type and model. When performing a functional test on starters, make sure the proper ground servicing equipment is available and in proper working condition.

CORROSION

When starters are removed for corrosion prevention or treatment, work should be performed in a clean, dry, well-ventilated area. Avoid prolonged inhalation of solvent fumes and skin contact with solvents.

Clean all non-electrical parts by immersion in a solvent conforming to federal specifications. Do not use a wire brush or metal wool at any time. Blow out internal passages carefully with filtered compressed air. Electrical parts must be cleaned by wiping with a lint-free cloth moistened with a solvent conforming to Federal Specification P-S-661B.

The most effective way of maintaining equipment in a corrosion-free state is to keep the outer surface finish clean and in the proper condition. This may be accomplished by the use of paints, primers, sealants, or preservatives as appropriate.

Inspection for corrosion is a continuing problem and should be handled on a day-to-day basis. Most Periodic Maintenance Requirements Manuals are complete enough to cover all parts of the aircraft and no part should go unchecked.

CHAPTER 10

D-C VOLTAGE REGULATION AND CIRCUIT PROTECTION

CARBON-PILE REGULATORS

Carbon-pile voltage regulators are used to maintain a substantially constant generator voltage despite variations in generator speed and load conditions. They also equalize generator load in installations involving two or more generators operating in parallel. These units are essentially automatic generator field rheostats that maintain a constant output voltage by controlling the generator field current automatically.

These regulators employ a stack of carbon washers (carbon pile) for the variable resistance element which controls the generator field current. When the stack of carbon washers is compressed, the resistance is at a minimum. As the pressure is released, the resistance increases. The resistance of the carbon stack is automatically varied by the action of an electromagnet coil and the spring tension on the movable armature assembly. (See fig. 10-1.)

OPERATING PRINCIPLES

Figure 10-1 (A) is a simplified schematic diagram of a d-c carbon-pile voltage regulator. When the generator armature first begins to rotate, the wafer-spring holds the carbon stack under maximum compression (low resistance) so that the voltage produced by the generator's residual magnetism causes sufficient current flow in the generator field windings. If the carbon stack remained compressed, the generator voltage would rise in proportion to the armature speed and would soon exceed the recommended line voltage. However, the electromagnet coil (potential coil) is connected across the main line of the power supply system and any increase of line voltage causes an increase of current flow in the electromagnet coil. The magnetic force set up by the coil opposes the armature spring and proportionally reduces the compression on the carbon stack, increasing the resistance.

The carbon stack, being in series with the generator shunt field, reduces the flow of current through the generator field coils. In accordance with a previous adjustment, a balance point is then reached between the action of the armature spring and the magnetic pull of the coil, to maintain the proper amount of field current in the generator for correct line voltage. This line voltage is then automatically maintained irrespective of generator variations in speed and load. Figure 10-1 (B) shows a more complete schematic which includes an equalizer circuit that is used when generators are connected in parallel. This is explained later.

Figure 10-2 shows a cutaway view of a typical carbon-pile voltage regulator. Following is a brief description of the major parts of this regulator.

The carbon washers are enclosed in a ceramic tube to insulate them from the frame. They are normally under compression (low resistance) between the pile screw contact plug and the contact plug of the armature. The number and type of washers varies with the different regulators. Some employ all washers of the same thickness, while others have ''scrambled'' stacks made up of alternately thick and thin carbon washers.

The resistors in series with the electromagnet coil consist of one fixed resistor and one variable resistor. The variable resistor (rheostat) is necessary to adjust the line voltage when installing the regulator, since test stand lead resistance usually varies from that on the aircraft. The fixed resistor has the greater resistance and therefore causes the greater voltage drop and dissipates the most heat. This permits the use of a smaller rheostat which provides for a finer adjustment of the current flow in that circuit. A spring clip engages a knurled flange on the adjusting nut assembly to prevent accidental change of the rheostat setting. The

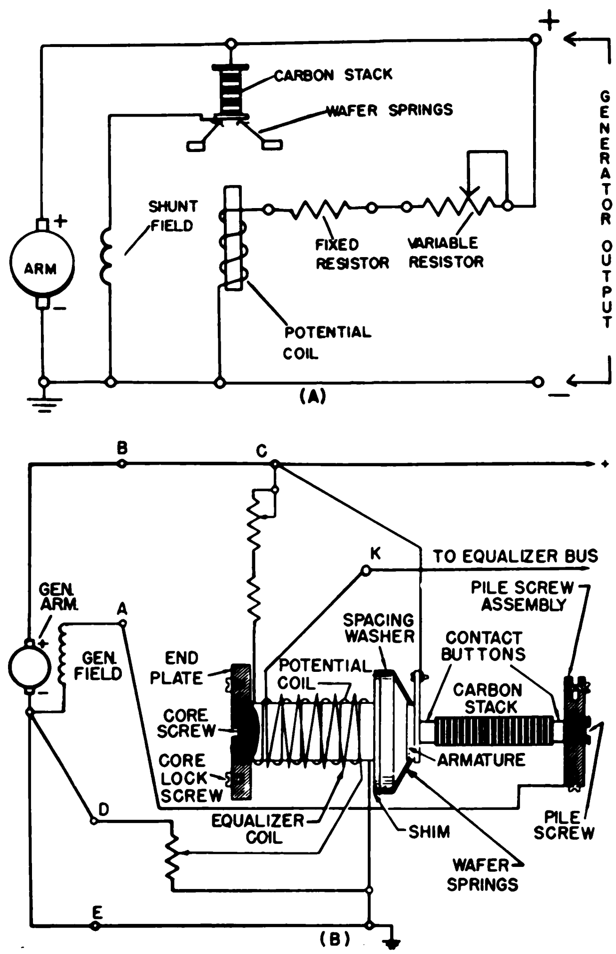


Figure 10-1.—Schematic diagram of d-c carbon-pile voltage regulator.

resistance winding of the rheostat is contacted by a sliding arm.

The core screw forms the electromagnet core and is made of soft iron. It is screwed into the end plate and held in place by core locking screws.

The temperature compensating metallic ring which encircles the magnetic core is in contact with the inside wall of the magnet case. This ring enables the regulator to maintain a steady generator voltage for the regulator's range of operating temperatures. The resistance of copper wire increases with an increase in temperature and decreases with a decrease in temperature. As a result, changes in regulator temperature cause changes in the resistance of the magnet coil winding; thus the magnetic flux induced by the coil, which links the armature and the core, is changed. This variation in flux, if not compensated for, causes a change in the magnetic attraction of the core for the armature and would produce excessive drift in the generator voltage.

The temperature compensating ring has a magnetic reluctance (resistance to the passage of magnetic flux) which varies directly with temperature. With an increase in regulator temperature, the reluctance of the magnetic path between the magnet case and the core is increased and a greater proportion of the magnetic flux induced by the magnet coil links the core and armature. With a decrease in temperature, the reluctance of the magnetic path between case and core is decreased and a greater proportion of the induced flux is short-circuited around the armature. As a result, the magnetic flux linking the armature is reduced.

The temperature compensating ring counteracts the effect of temperature on the flux linking the core and armature. As a result, the tendency of the regulator to drift with changes in temperature is reduced.

The finned pile housing radiates the heat developed during regulator operation.

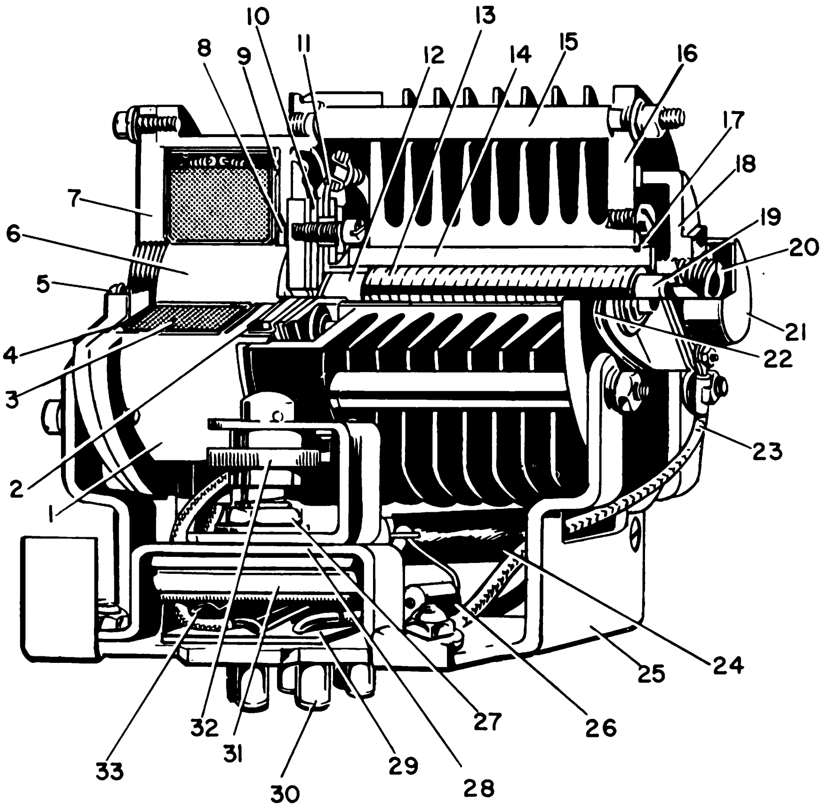
Ther terminal contacts extending through holes in the base provide for circuit connections. These make connections with contact blades in the shock-mounted base.

ADJUSTMENT

The following adjustment procedure is typical for most carbon-pile regulators. However, each model has its own peculiarities and the proper procedure for each model will differ slightly. The following procedure is to be used only for the General Electric No. CR2781-M155D1 regulator.

Equipment Required

It is preferable to use the same type of generator for adjusting the regulator that will be used with the regulator in service. However, it has been found that satisfactory regulator adjustment can be obtained when any aircraft generator is used for adjustment that has the same or a higher capacity than the one to be used with the regulator in service. That is, a regulator adjusted on a 400-ampere generator will usually work well on a 200-ampere generator, but the



1. Magnet case.
2. Armature stop shim.
3. Electromagnet coil.
4. Paper packing washer.
5. Core locking screw.
6. Magnet core.
7. End plate.
8. Temperature compensating ring.
9. Coil clamping spring.
10. Diaphragm armature assembly.
11. Ferrule.
12. Contact button.
13. Carbon pile.
14. Pile tube.
15. Stud.
16. Pile housing.
17. Tube lock.
18. Pile adjusting screw bracket.
19. Contact button.
20. Pile adjusting screw.
21. Cap.
22. Mica insulator.
23. Lead assembly.
24. Tubular resistor.
25. Base.
26. Stabilizer resistor.
27. Rheostat mounting nut.
28. Clip and bracket assembly.
29. Insulator.
30. Terminal contacts.
31. Rheostat.
32. Adjusting nut assembly.
33. Sliding arm.

Figure 10-2.—Cutaway view of d-c voltage regulator.

reverse is not true. The General Electric Model 2CM-76-C4 generator is installed in many naval aircraft using the subject regulator. The rpm values in this procedure are for the 2CM-76-C4 generator. These values may be different if another generator is used.

The test assembly shown in chapter 7 is the recommended test fixture for adjusting voltage

regulators. If other equipment must be used, the procedure may need some modification.

Any generator drive stand capable of driving a 400-ampere generator fully loaded and at given speeds is satisfactory. The test stand shown in chapter 7 was used for the preparation of this procedure.

To correctly adjust the regulator for the 27.7 volts required, it is necessary that the voltmeter being used be capable of producing a readable measurement with an accuracy of 0.1 volt. A recently calibrated and carefully handled PX-14 or similar voltmeter will meet these requirements. The voltmeter on the test assembly cannot be read as accurately as the PX-14.

A pair of headphones will be needed to check the stability of the regulator. A phone jack is provided on the electrical test assembly for connecting the headphones.

Characteristic Curve

A typical pile screw characteristic curve is shown in figure 10-3. Point A is the first peak of generator voltage as the pile screw is turned inward (clockwise) from a full out position. Point B is the proper adjustment point, a point near A where the full-load voltage and no-load voltage of the generator are the same.

CAUTION: Point D can be obtained on a regulator of this type that has a full-load and no-load voltage of the same value at 27.7 volts. If a regulator pile screw is adjusted for point D and the regulator is installed in an aircraft, excessive generator voltage may be experienced with a temperature change in the regulator. Point D is the improper adjustment point—avoid adjusting here. Point C is shown because it is desirable to check on the condition of the regulator at this point. Do not shock-load the regulator with the pile screw near point C on the curve.

PROCEDURE FOR TESTING AND ADJUSTING:

1. Connect the equipment as shown in figure 10-4. Make certain that proper size wire is used and that all connections are clean and tight.

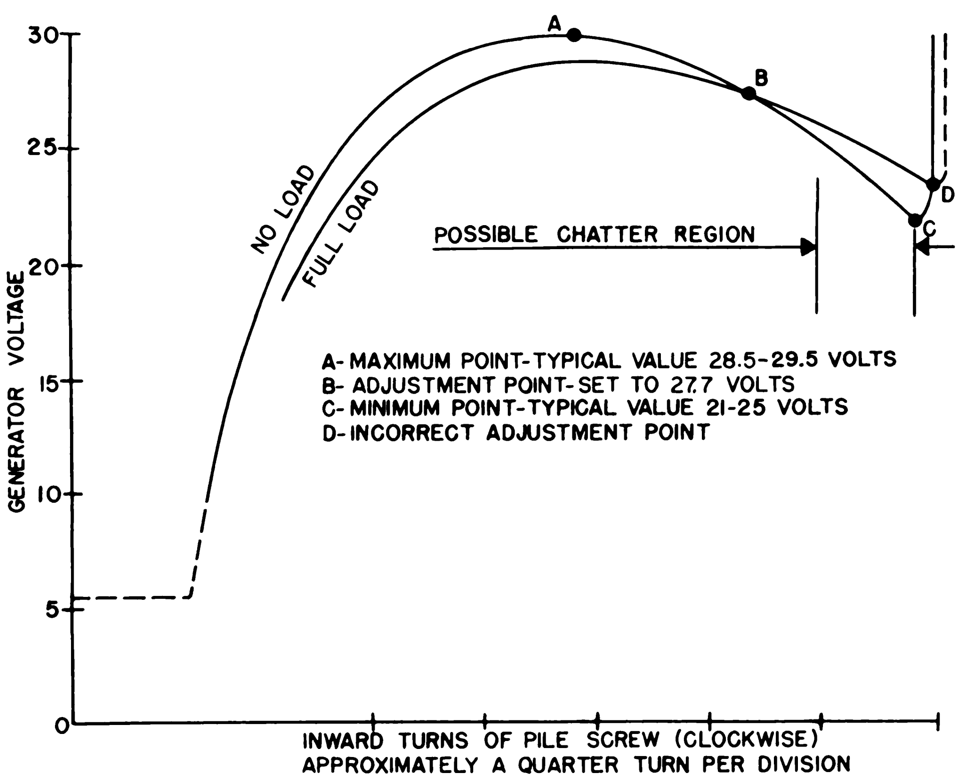


Figure 10-3.—Typical pile screw characteristic curve.

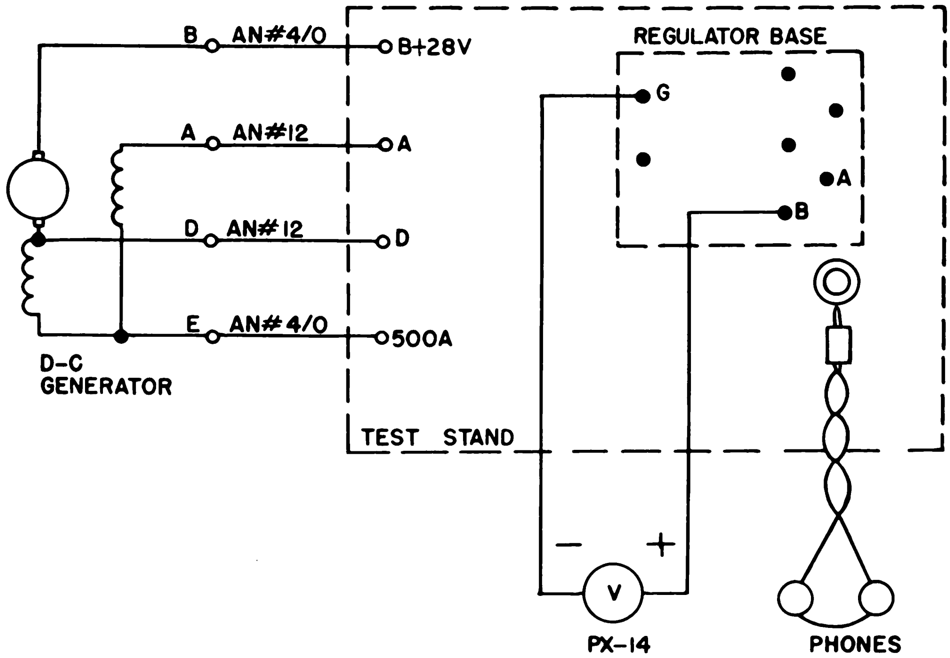


Figure 10-4.—Test wiring diagram.

2. Connect the POS lead of the PX-14 voltmeter to terminal B of the voltage regulator base, and the NEG lead to terminal G. This connects the voltmeter across the generator output.

CAUTION: Terminals A and B of the voltage regulator base are near each other. A short from A to B will cause excessively high generator voltage. Be sure not to short these two terminals with the POS lead of the voltmeter.

3. Inspect the regulator for wiring discrepancies, such as wires too long or too short, wires not routed properly, wires chafed or overheated, cold-soldered joints, and other items that might cause failure.

4. Make sure that the four screws holding the magnet case to the frame are tight.

5. Measure the coils, resistors, and rheostat for proper resistance values. If the regulator parts are not within the range of resistances given in the Overhaul Instruction Manual, return the regulator to be overhauled.

6. Set the voltage regulator rheostat to its mechanical midposition.

7. Mount the regulator on the base provided on the test assembly.

8. Set all switches and links on the test assembly to their proper positions. See the Operation and Service Instruction Manual, NavAer 17-15BA-517, to determine the proper settings of the switches and links.

9. Turn the pile screw out (counterclockwise) as far as it will go.

10. Start the cooling fans for the load-bank.

11. Start the generator and bring it up to 4,500 rpm. The generator voltage shown on the PX-14 voltmeter should be less than 10 volts. If not, the carbon pile is too long and 1 washer should be removed. Recheck for a generator voltage of less than 10 volts.

12. Increase the generator speed to 8,000 rpm.

13. Turn the pile screw in (clockwise) slowly. The generator voltage will rise to a maximum at point A on the characteristic curve (fig. 10-3). The voltage at point A should be between 28 and 30 volts.

14. Continue slowly turning the pile screw in a clockwise direction until the generator voltage falls about 1 volt below point A. This is the approximate position of point B.

15. Fully load and unload the generator to determine point B, the point where the full-load and no-load voltages are the same. If the full-load voltage is lower than the no-load voltage,

turn the pile screw in; if it is higher, turn the pile screw out.

16. When point B is established, loosen the magnet locking screw and turn the body in (clockwise) slightly if the generator voltage is higher than 27.7 volts. If the generator voltage is below 27.7 volts, turn the magnet body (core screw) out (counterclockwise) slightly. Tighten the magnet locking screws uniformly, making certain to establish point B at 27.7 volts with the magnet locking screws tight. (NOTE: In this procedure 27.7 volts is specified as the voltage to which the regulator should be adjusted. The varying effects of climatic and operating conditions will sometimes dictate a change in this setting.)

17. Set the test assembly d-c voltmeter circuit selector switch to the PILE V position.

18. Reduce the generator speed, with no load on the generator, to approximately 3,500 rpm; then adjust the speed until the pile voltage is 13 volts. Allow the generator to operate at this speed for 15 minutes to bring the regulator up to operating temperature.

19. Turn the test assembly d-c voltmeter circuit selector switch to the INVERTER INPUT or GEN V position.

20. Increase the generator speed to 8,000 rpm.

21. Listen carefully on the headphones while shock-loading (applying and removing full-load to generator) the regulator to detect instability. A stable regulator produces a humming noise or steady roar. A rapid series of popping noises indicates instability.

22. If the regulator is unstable, replace the carbon-pile stack and readjust the regulator.

23. With the generator at 8,000 rpm, turn the pile screw in (clockwise) until voltage reaches its minimum, point C.

24. Note the voltage at point C and calculate the voltage difference between points B and C. This voltage difference is normally 3 to 6 volts. If it is less than 0.7 volt, return the regulator to be overhauled.

25. Return the pile screw setting to point B. CAUTION: The pile may chatter near point C; therefore, pass through this region as quickly as possible to prevent damage to the carbon-pile disks. Do not shock-load the regulator near point C as this may induce chattering.

26. Establish the exact position of the pile screw for point B by checking the full-load and no-load regulated voltage at 8,000 rpm generator speed. Readjust the magnet body, if necessary, to the 27.7 volts value for point B. Make sure the magnet locking screws are tight.

27. Record the no-load and full-load voltages at 4,500, 6,000, and 8,000 rpm. The regulated voltage should remain between 27.2 and 28 volts for these speeds.

28. If the voltage does not remain between these limits, turn the pile screw in slightly and recheck the preceding step.

29. Increase the generator speed from 4,500 to 8,000 rpm without shock-loading; then note generator voltage.

30. Shock-load the regulator several times and note the no-load voltage. The difference between these two readings should not be greater than 0.3 volt. If it is greater, replace the carbon disks and check the insulation tube for cleanliness and cracks.

31. With the generator at 6,000 rpm, note the regulated voltage. Press the EQUALIZER TEST button on the test assembly. The regulated voltage should drop a few volts. If the voltage does not change, check for an open equalizer circuit. If the voltage rises, check for reversed equalizer connections.

32. With the generator running at no-load and 6,000 rpm, move the rheostat through its travel to determine if it will adjust the regulated voltage from 26 to 30 volts. If not, check the resistance of the rheostat for proper value.

33. After this check, set the rheostat for a generator voltage of 27.7 volts no-load at 6,000 rpm.

INSTALLATION

When you are installing a regulator in an aircraft, the location, in most cases, has been determined by the manufacturer. However, since numerous modifications are performed, there may arise many occasions when you should know the following in connection with mounting a regulator in an aircraft or in the maintenance shop.

Regulators that have been in storage require preparation prior to installation. Check all electrical connections carefully for cleanliness and security. The regulators should also be bench tested before installation to insure proper setting as well as proper operation. Instructions in the appropriate technical manuals should be followed.

Even through the shock mount of the regulator reduces the effect of aircraft vibration on the regulator to a minimum, it is advisable to mount

the unit in a location not subject to excessive vibration or exposed to oil or water spray. When selecting a location, consideration should be given to adequate ventilation and to the accessibility of the regulator for routine inspection and servicing, as well as to the shortest possible lengths of cable to complete the installation wiring. If possible, it should be mounted with the pile axis horizontal and at right angles to the main axis of vibration of the aircraft.

In installing the regulator, be careful to avoid locations subject to high temperatures during operation. High temperatures affect operation and service life by charring lead and coil insulation, causing drift in the regulator setting, and rapid deterioration of the carbon pile. Failure due to high temperatures will require replacement of leads, coils, and the pile.

The other major factors affecting service life are vibration, the generator being controlled, and the load conditions. Even minor decreases in the regulator operating temperature will result in a considerable lengthening of the regulator life. Safe temperatures can be maintained only by adequate ventilation of the compartment in which the regulator is installed. Ventilation may be by either forced cooling or natural convection. If forced cooling is used, consideration should be given to ventilation in the event of failure of the cooling air supply during operation.

When replacing a regulator in an aircraft, carefully inspect the regulator base prior to installing the new regulator. Make sure the four screws holding the regulator base and the bonding wire are secure. The steps to follow are:

1. Install the regulator in its base and secure it firmly.
2. Warm up the regulator by 20 to 30 minutes of engine turnup.
3. Check the generator regulated voltage value at maximum allowable engine rpm with a good PX-14 voltmeter. Set the voltage to 27.7 volts with the rheostat.

If it is found impracticable to operate the engine as required by the above, then it is preferable to install and operate the regulator as adjusted on the test stand rather than to adjust the rheostat with the regulator cold. If the rheostat is not adjusted at the time of installation, then it would be extremely desirable to do so during or immediately after the first flight (while the regulator is still hot).

CIRCUIT PROTECTORS

OVERVOLTAGE RELAYS

In recent years, d-c electrical power systems in modern aircraft have been equipped with protective devices (overvoltage relays) for prevention of damage which might result from excess voltage. If the generator produces an overvoltage (a condition which sometimes occurs momentarily, due to power surges), the overvoltage relay will automatically open the field circuit of the generator. The upper limit of voltage is usually set at 31 to 33 volts. The overvoltage unit consists of two relay coils, the TRIP coil and the RESET coil. When the overvoltage condition occurs, the trip coil is energized and the field circuit of the generator is thus opened. The relay may be reset by placing the generator control switch in the RESET position. This energizes the reset coil of the overvoltage relay, closing the generator field circuit again, but the generator will not operate until its control switch is returned to the ON position. If the circuit trips a second time, further operation of the generator should not be attempted until the trouble has been investigated.

UNREGULATED TRANSFORMER-RECTIFIERS

Some of the more recent aircraft do not have d-c voltage regulators, because their primary electrical systems use alternating current. The transformer-rectifier is the conversion unit for obtaining d-c power in these systems. This unit depends upon the regulation of the a-c system and upon its own regulation characteristics. An understanding of the voltage-regulation characteristics of the transformer-rectifier requires some knowledge of its construction and overall operation.

The transformer primary coil is delta connected to its a-c generator. (See fig. 10-5.) The transformer secondary is a variation of a basic single-wye, six-phase, star-connected circuit and employs interphase transformers, ripple filter chokes, radio noise filters, and 12 silicon diodes. Since the six secondary phases are split, each diode carries current during one-twelfth of each cycle. Thus when the output of the secondary is rectified and combined, the voltage overlaps smoothly, producing only a very

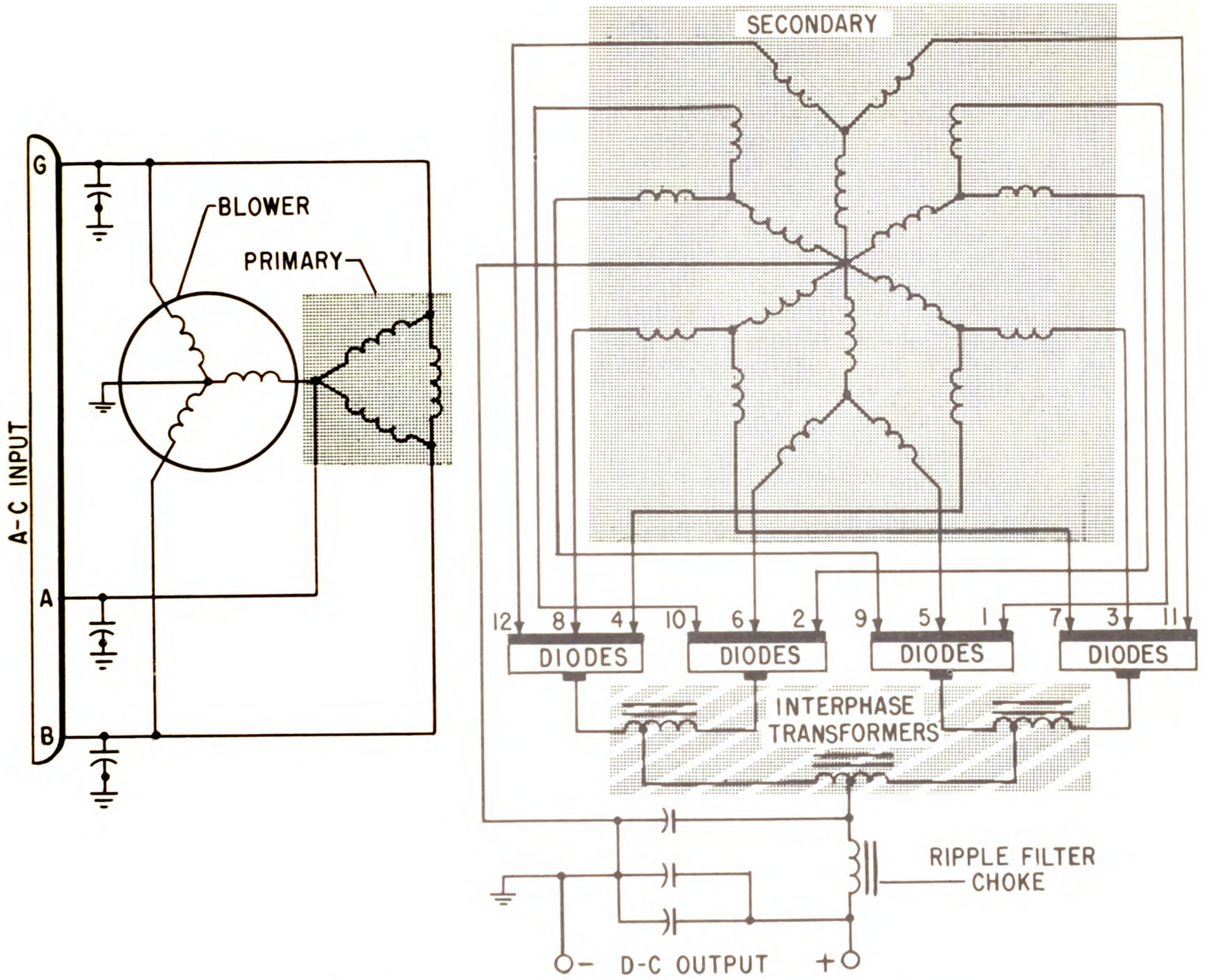


Figure 10-5.—Transformer-rectifier; schematic diagram.

small ripple in the final d-c output. The interphase transformer helps to divide the current equally between each phase. Transformer cooling is provided by a fan that operates continuously when the transformer-rectifier is energized.

Since the transformer-rectifier is a nonregulated unit, it must operate with at least 10 percent load to prevent excessive variation in output voltage. This is accomplished by means of resistor load banks which are automatically connected to the transformer-rectifier during periods when the overall d-c load is greatly reduced. Usually, an aircraft will contain two or more transformer-rectifiers and these are normally both energized and carry the complete d-c load together. In the event of failure of one transformer-rectifier, its load can be switched manually to another which is still in operation.

REVERSE-CURRENT RELAYS

The reverse-current relay is an automatic switch installed in the power supply system between the generator and the battery.

When the generator voltage is above battery voltage, the relay closes, connecting the battery to the generator. When the generator is stopped or its voltage output is below battery voltage, the reverse current from the battery causes the relay to open, thus preventing battery discharge.

The reverse-current relay shown in figure 10-6, although it has limited use in aircraft, will be used to illustrate the basic principles of reverse-current relay operation. This fixed voltage type relay is still widely used in battery charging work as well as in automotive and small aircraft applications.

This reverse-current relay employs a potential coil and a series coil wound on the same core to actuate the relay contacts. When the generator armature begins to rotate, current flows through both the potential and the series coils. As the generator voltage increases, the current through these coils increases. The fluxes produced by these coils are additive. When the generator voltage reaches about 26.5, the current through the coils produces adequate flux to close the relay contacts. This permits current to flow to the battery and to other loads. All of this current must pass through the series coil. This load current produces additional magnetism which aids in holding the relay contacts firmly closed. The contacts remain closed as long as the generator is supplying current to the load.

When the engine is throttled down, the generator voltage is decreased. When the generator voltage becomes lower than the battery voltage, current flows from the battery to the generator (reverse current). The direction of current flow through the potential coil remains the same.

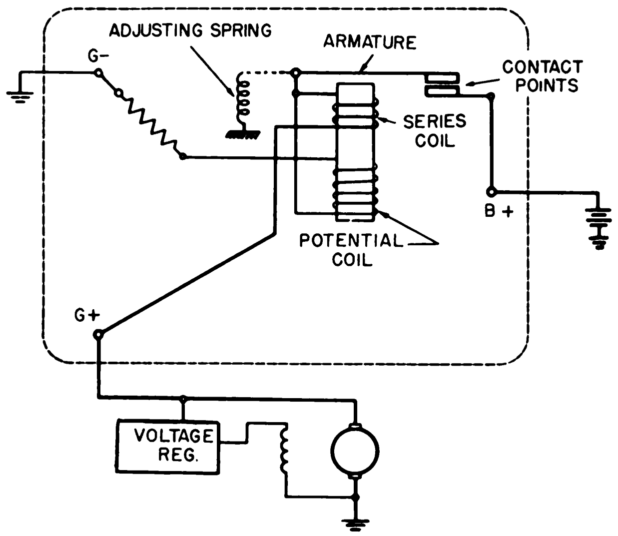


Figure 10-6.—Internal connections of a reverse-current relay.

The magnetism produced by the reverse current through the series coil opposes that of the potential coil, and the contacts open, disconnecting the generator from the load.

The relay closing voltage is adjusted by changing the armature spring tension. While aircraft that are equipped with this type relay are taxiing, the generator switch should be in the OFF position. This prevents the relay from chattering due to acceleration and deceleration of the engines.

Differential Reverse-Current Relay

The differential voltage type reverse-current relay was developed to overcome the contact chattering difficulties experienced with the fixed voltage type on multigenerator systems. Current reversals were inherent, particularly under conditions of light electric load, when the relays did not have identical voltage adjustments and when there was considerable differences in the resistance of the generator leads. The rapidity with which the various generators were disconnected and connected to the system caused deterioration and welding of the main contacts of the reverse-current relay. The differential voltage type reverse-current relay measures the difference between generator voltage and the system voltage, and prevents operation, until a predetermined voltage difference exists. Hence, the system voltage may vary over a wide range without objectionable chatter when the the differential voltage type reverse-current relay is used.

The following paragraphs discuss the details of construction and the principles of operation of the AN3025-300 (type A-700A) differential voltage generator control relay.

The differential type reverse-current relay, as illustrated in figure 10-7 prevents reverse current, in excess of 25 amperes, from flowing from the battery or bus to the generator of an aircraft electrical system. The differential voltage type of relay prevents this reversal of current by automatically disconnecting the generator from the battery or electrical bus system when the generator's voltage drops below the voltage of the battery or that of the bus. The reverse-current relay will automatically reconnect the generator to the battery or electrical bus when the generator's output voltage exceeds that of the battery or electrical bus system.

The relay may also be used as a starting contactor, as well as a reverse-current relay,

for auxiliary powerplants which are to be started by applying battery voltage to the generator.

The voltage relay (fig. 10-7 (A)) consists of a permanent magnet armature (1) pivoted between the pole faces (2) of the relay frame (3). Because the armature is a permanent magnet, the relay will not operate unless the voltage applied to the coil is of the correct polarity.

The relay coil has approximately 480 ohms resistance and is designed to close its contacts between 20 and 24 volts if the generator builds up in the correct direction. If the generator is faulty and builds up reverse voltage, the relay will not close.

A spring (4) is attached to the armature so that the voltage relay will open when the voltage drops to 18 volts.

The differential relay (fig. 10-7(B)) is similar in construction to the voltage relay and also uses a permanent magnet armature (5). The only difference between these relays is that the differential voltage relay has two coils. These are wound in opposite directions so that one coil instead of a spring will return the armature.

One of these coils (6) is wound with fine wire. It has a resistance of approximately 5 ohms and is designed to close the relay when the voltage difference between the generator and bus is greater than 0.35 to 0.65 volt, and the generator voltage is greater than the bus voltage.

The series coil (7) is a current coil arranged to open the relay when the current is between 16 and 25 amperes and in a reverse direction flowing from bus to generator.

The contactor is a solenoid type switch and consists of a coil, magnetic frame (9), and movable core (10). When voltage is applied to the coil in excess of 10 volts, the plunger is attracted by the magnetic frame. As the plunger moves up in the coil, the movable contacts (8), which are attached to the core rod (11), close the circuit and connect the generator to the bus. These main contacts are rated at 300 amperes. The contacts will remain closed until reverse current opens the differential voltage relay, which opens the contactor coil circuit and permits the main contacts to open.

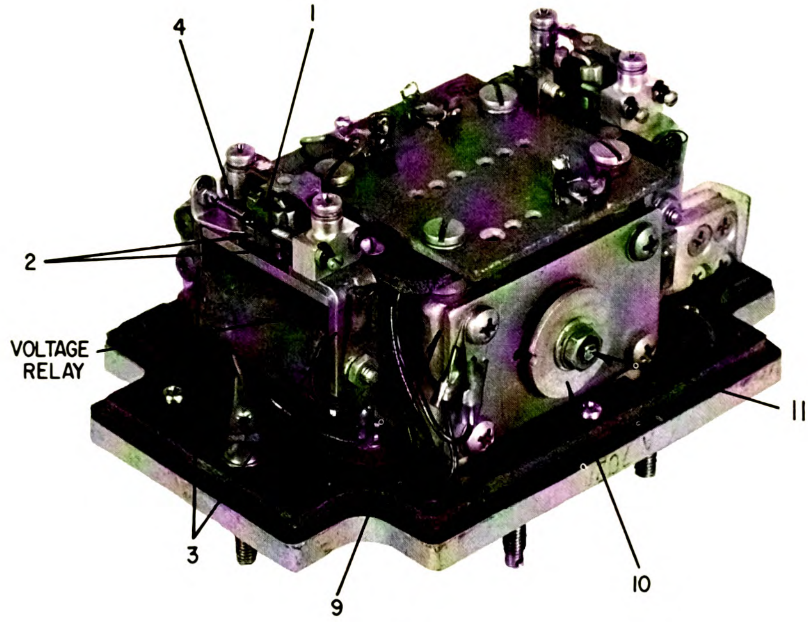
PRINCIPLES OF OPERATION.—The heart of this device is the polarized differential relay. This is an electromagnetic switch with a permanent-magnet armature. The opening and closing of this armature is, therefore, dependent upon the direction of current flow in the coil.

The sequence of operation is explained in figure 10-8. When the generator voltage reaches approximately 22 volts, the polarized voltage relay (1) will close if the generator control switch is closed. This energizes the fine wire coil of the polarized differential relay (2) which is connected across the main contacts. At this time these main contacts are in the open position. The voltage on the coil of relay (2) is now the difference between generator voltage and that of the bus, or battery voltage. When this voltage reaches a value between 0.35 and 0.65 volt and is of the correct polarity (generator voltage must be higher than the bus voltage), the differential relay coil magnetizes the associated iron core material and trips the differential relay contact. This contact closes the circuit between the generator output and the coil of the main contactor, energizes the contactor coil, and closes its normally open contacts joining the generator to the bus. The closing of the main contactor shorts out the differential voltage coil (2); however, its contacts will remain closed because of the magnetic attraction of the permanent-magnet armature.

During operation, if the generator voltage drops below the value of the bus voltage, current will flow through the generator to the bus. This action attempts to drive the generator as a motor. The reverse current flows through the reverse-current coil. When its value reaches from 16 to 25 amperes, the resulting magnetic field in the core of the differential relay forces the pivoted permanent-magnet armature to open the differential relay contacts. This opens the circuit containing the coil of the main contactor, and thus its contacts open which, in turn, disconnects the generator from the bus. As the generator voltage decreases to 18 volts, the voltage relay (1) will open.

You may see by referring to figure 10-8 how this reverse-current relay also serves as a generator relay. Opening the generator control switch will deenergize both the voltage relay (1) and the main contactor relay (3) which disconnects the generator from the bus. Closing the switch will likewise connect the generator to the bus.

On multigenerator aircraft the differential relays on all of the generators do not close when the load on the generators is light. For example, in an aircraft having a load of only 50 amperes, only two or three relays may close during takeoff. If a heavy load is applied, the equalizing circuit will lower the voltage of the generators already on the bus and at the same time raise the voltage of the remaining generators allowing



1. Permanent magnet armature.
2. Pole faces.
3. Relay frame.
4. Spring.
5. Permanent magnet armature.
6. Coils.
7. Series coil.
8. Movable contacts.
9. Magnetic frame.
10. Movable core.
11. Core rod.

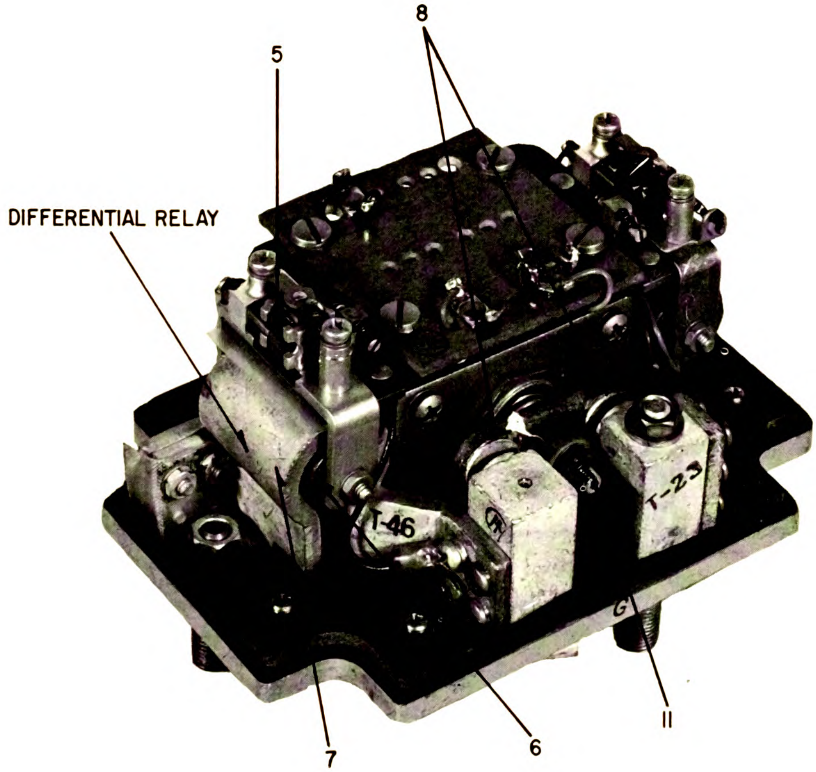
Figure 10-7(A).—AN-3025-30-300 (type A-700A) differential voltage generator reverse-current relay

their relays to close. If the generators have been paralleled properly, all the relays stay closed until the generator control switch is turned off or until the engine speed falls below the minimum needed to maintain generator output voltage.

TESTING.—Reverse-current relays must be bench tested when there are indications that they are operating improperly in the aircraft. The procedure to be used when testing the AN-3025-300 (type A-700A) cutout, using a test stand, is given as a typical example. The circuit shown in figure 10-9 is used in this presentation. Connect the relay into the circuit as shown in figure 10-9 without removing the cover.

DIFFERENTIAL VOLTAGE AND REVERSE-CURRENT OPERATION:

1. Set all switches in the OFF position.
2. Operate the generator on the test stand at about 4,000 rpm (for a high speed generator).
3. With SW1 in position 1, adjust the generator voltage by means of R1, the field rheostat, so that the generator voltage is about 1 volt less than the battery voltage. Generator and battery voltage readings are obtained on V3, by placing SW5 in the 1 or 2 position.
4. With SW2 in position 1 and SW4 closed, place SW3 in position 2 and slowly increase the generator voltage by means of R1. When the relay operates, the voltage indicated on V2 will go to zero. The differential voltage is the reading JUST BEFORE V2 goes to zero, and should be between 0.35 and 0.65 volt.
5. SW3 must be set in the open position before performing the next test.
6. To measure the reverse current, slowly decrease the generator speed until the relay opens. This current is read at A1 and should be between 16 and 25 amperes. This will be the



(B)

Figure 10-7(B).—AN-3025-30-300 (type A-700A) differential voltage generator reverse-current relay—Continued.

reading just before the reading on A1 returns to zero.

7. Leave the differential relay contacts in the open position.

TESTING VOLTAGE RELAY:

1. Set all switches in the OFF position. Operate the generator at a speed of about 4,000 rpm.

2. For this test, the differential relay contacts must be in the open position.

3. Set SW2 in position 1, SW5 in position 1, and SW1 in position 1 and slowly raise and lower the voltage by means of R1. The closing voltage should be between 20 and 24 volts and is read on V3 when the relay operates. The opening voltage should be above 18 volts.

4. The contactor will not close with this switching arrangement, so it will be necessary to connect an ohmmeter from GEN terminal to T test terminal to indicate when the contacts have closed. Remove the nameplate and make a connection to terminal T (fig. 10-10) by means of a No. 6-32 screw, one-half inch or longer, screwed into the tapped hole at T.

5. After testing, remove this screw and replace the nameplate.

TESTING CONTACTOR:

1. Set all switches in the OFF position.

2. This test should be made before the coil has become heated.

3. This test should be made with the four mounting holes flat on the table. The position of the relay will have some effect on this operating voltage even though the relay may be mounted on the aircraft in any position.

4. Operate the generator at a speed of about 4,000 rpm.

5. With SW4 and SW3 open and SW1 in position 1 and SW2 in position 2, vary the voltage by means of R1 until the contactor closes and opens. It should close between 14 and 15 volts, and open below 5 volts.

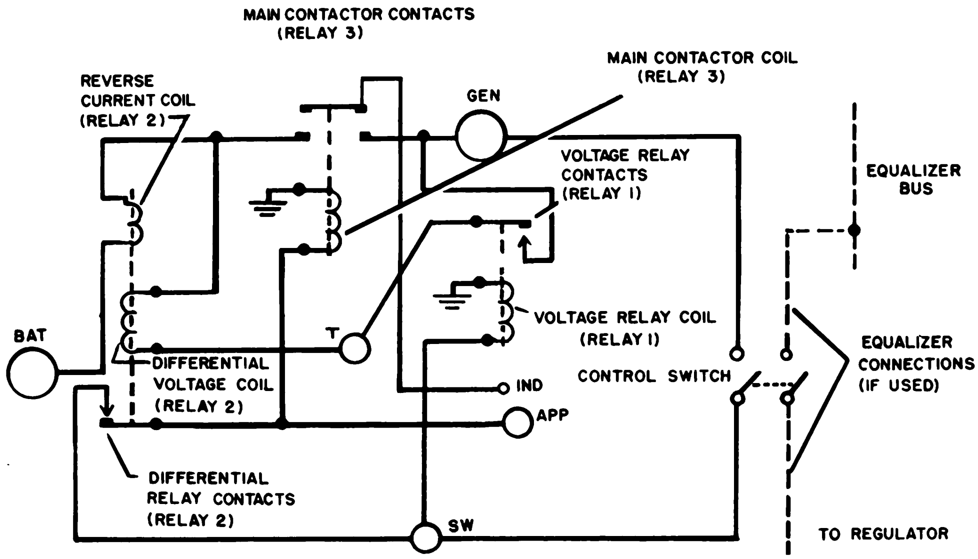


Figure 10-8.—Schematic wiring diagram, AN-3025-300 (type A-700A) generator reverse-current relay.

MEASURING MILLIVOLT DROP:

1. Set all switches in the OFF position.
2. Operate the generator at a speed of about 5,500 rpm. Set SW1 in position 2, SW2 in position 1, SW3 in the open position, and SW4 closed.
3. Adjust the regulator to 27.7 volts.
4. Close the load bank switches until 300 amperes are indicated on A1.
5. Place SW3 in position 1 and read the millivolt drop on V1. This should be less than 100 mv.

NOTE: Place SW3 in the open position before permitting the relay to open.

The differential relay contacts should be left in the open position after completing tests. Otherwise, serious damage to the relay will result if it should be installed in an aircraft having a generator of reversed polarity. To open these contacts, operate the relay in the normal manner.

As a result of these tests you should be able to determine if the relay is only out of adjustment or if needs repairs.

ADJUSTING:

In order to adjust the reverse-current relay it must be connected to a test panel as for testing. The steps for adjusting are as follows:

DIFFERENTIAL VOLTAGE RELAY (fig. 10-11 (A) and (B)):

1. To set the closing differential voltage, loosen locknut (1) and adjust screw (2) until the relay closes between 0.45 and 0.55 volt. Lock the adjust-screw (2) with the locknut (1).
2. Loosen the locknut (3) and adjust screw (4) until the relay opens between 0.33 and 0.36 volt and contact screw (5) is set so that when the relay is closed the contacts would engage for at least one-half turn if screw (5) is backed out. Lock the adjust screw (4) with the locknut (3). (Turning screw (2) clockwise will lower the closing voltage. Turning screw (4) clockwise will make it open at a lower voltage.) Tighten the locknut on screw (5).

VOLTAGE RELAY:

1. Adjust screw (6) until the relay armature gaps are equal. Lock with nut (7).
2. Adjust spring (8) by means of spring screw (9) and nuts (10) until the relay closes at 23.5 volts. Lock the nuts (10). Increasing tension of spring (8) will raise both the closing and opening voltage, decreasing tension will lower both voltages.
3. To change the opening voltage only, adjust screw (11) until the relay opens at 18.5 volts and with silver-tipped contact screw (13) set so that when the relay is closed the contact would remain closed for at least one-half turn if the screw (13) is backed out. Lock the screw (11) with nut (12). Tighten locknut on screw (13).

MAIN CONTACTOR:

1. The gap (14) between the core rim and the frame should be adjusted to 0.093 inch. This gap represents the total movable core travel. To adjust this gap, loosen the locknut (15) and screw

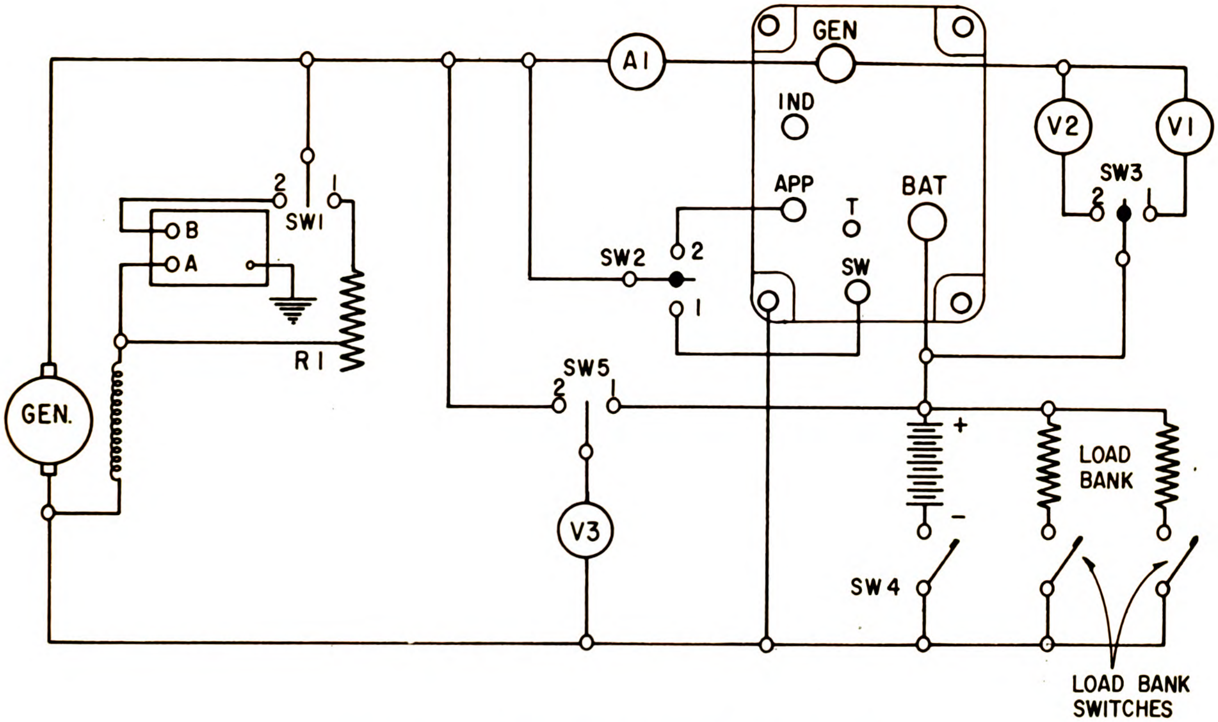


Figure 10-9.—Test circuit (using test stand).

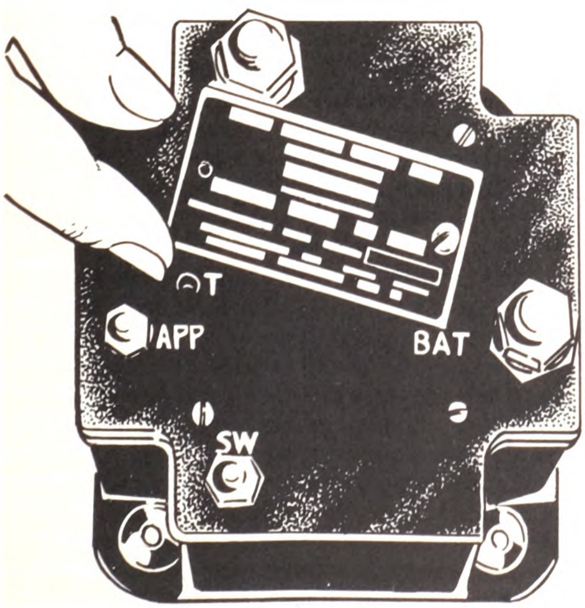


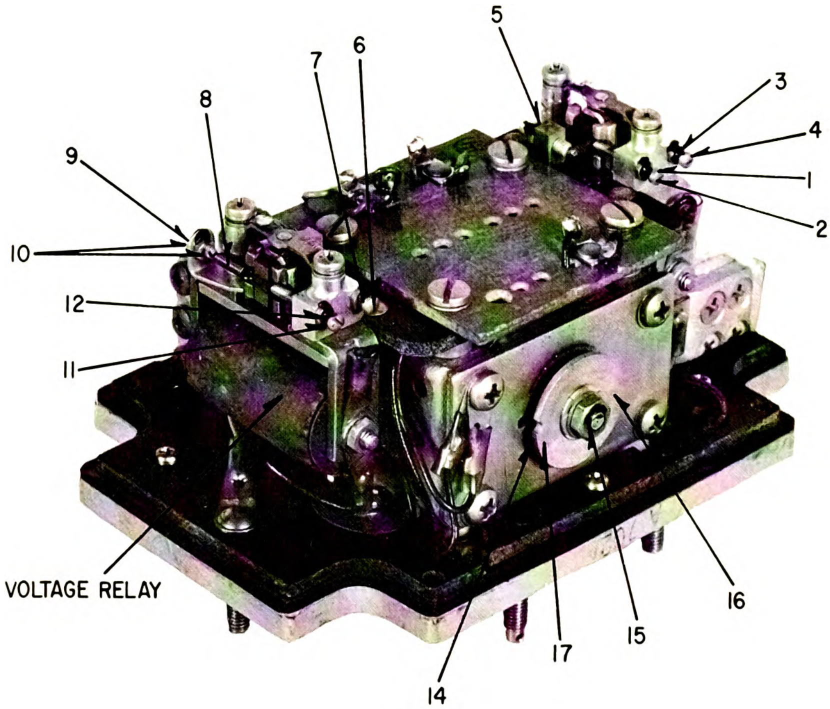
Figure 10-10.—Location of test terminal T.

the movable core (16) in or out. The core can be held while locking and tightening nut (15) by inserting a 3/32-inch rod or drill through the notch (17) in the shoulder of the core into a matching hole in the frame.

2. The contact overtravel (amount the core moves after contacts touch) should be adjusted to approximately 0.020 inch. This adjustment is made by loosening the locknut (18), making the adjustment, and then tightening the locknut. If the overtravel is too great, the contacts will not be "pulled in" by 15 volts, and a correct adjustment should be made.

TROUBLES AND REMEDIES.—It is general practice to replace rather than to repair differential relay units in the field. Procedure, however, is guided by the type of repair required and availability of replaceable units, as well as repair facilities. Table 10-1 will prove helpful in servicing and maintaining reverse-current relays.

PREFLIGHT INSPECTION.—Observe the instrument panel voltmeter and ammeter for closing voltage and relay opening on reverse current.



(A)

1. Locknut.
2. Screw.
3. Locknut.
4. Screw.
5. Screw.
6. Screw.
7. Locknut.
8. Spring.
9. Spring screw.
10. Locknuts.
11. Screw.
12. Locknut.
13. Screw.
14. Gap.
15. Locknut.
16. Movable core.
17. Notch.
18. Locknut.

Figure 10-11(A).—Reverse-current relay adjustment points.

As the engine rpm is increased from idling, the generator voltmeter reading should increase accordingly. As the generator voltage exceeds the battery or bus voltage by 0.35 to 0.65 volt, there should be a momentary dip in the voltmeter reading. This indicates that the relay has closed at the proper voltage and has connected the generator to the load. It may be necessary to put a slight load on the system, such as an inverter, before the voltmeter will show a dip.

Proper opening of the relay (if the battery is not too discharged) can also be determined by the generator ammeter. If the engine rpm is decreased, the voltage regulator will hold the voltage constant until the generator speed is reduced below minimum generator operating rpm. Continued reduction of rpm causes a continued reduction of generator voltage until it is actually below battery voltage.

When the battery has the greater voltage, a reverse current will flow from the battery to the generator. This is indicated on the ammeter by a below-zero reading. The pointer should flick back to zero, showing that the relay has opened the circuit. A continued below-zero reading suggests that either the relay has failed to open

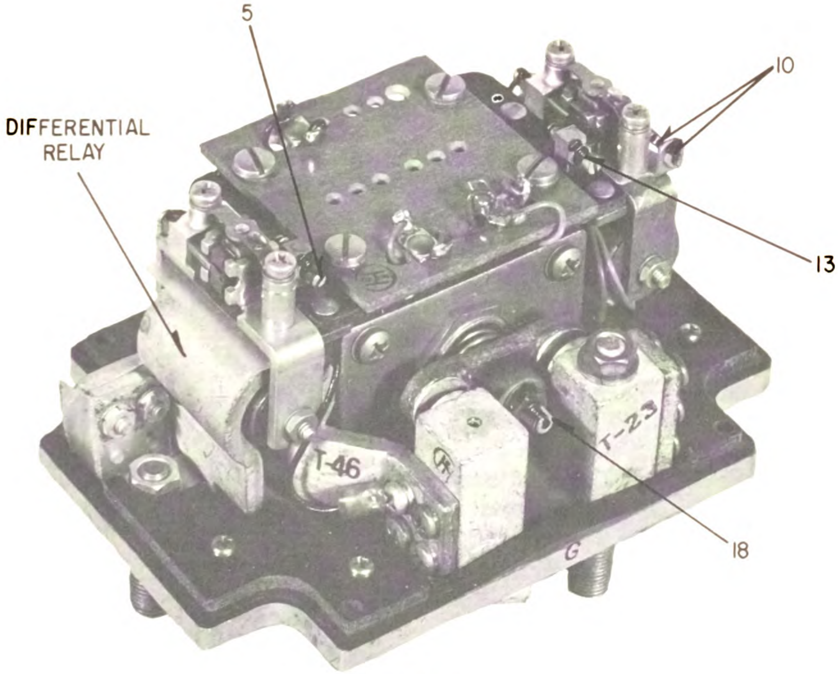


Figure 10-11(B).—Reverse-current relay adjustment points—Continued.

or the ammeter pointer is stuck. This latter possibility can usually be eliminated by tapping the meter case or panel lightly with the fingers.

PERIODIC INSPECTION.—Inspect the main contacts for damage due to arcing. These may appear to be pitted or burned, but unless they are fused or melted they will not need to be replaced. The contact spring should be replaced if discolored from heat. Replace any parts which appear to be worn, burned, broken, or distorted. Examine coil leads for broken insulation.

In all cases of failure or improper operation of the d-c power system, investigate the trouble at the earliest opportunity to prevent further damage to the components. The generator ammeters and voltmeters on the instrument panel will indicate the presence of such troubles. Troubleshoot the generator only after a thorough inspection of the control system, with particular attention to the instructions furnished for the voltage regulator and the reverse-current relay.

D-C GENERATOR PARALLELING

In many aircraft the electrical power requirements are much higher than can be furnished with one generator. For this reason, two or more generators are usually installed and their power is combined or paralleled. This means that their output is connected to the same bus. When operating two or more generators in parallel, it is essential that each generator take its proportional share of the total load so that one may not be required to produce more than its maximum rated current while another runs underloaded. To equalize the load between generators it is necessary to make each generator produce exactly the same voltage. Although the voltage of each generator is closely controlled by its voltage regulator, the voltage of each may not be the same for all loads. If two or more generators which do not maintain exactly the same voltage are connected to the same bus, large circulating currents will flow between them. These circulating currents waste energy and heat the generators. Because of this, a means

Table 10-1.—Troubleshooting chart.

Trouble	Probable cause	Remedy
Voltage relay will not close.	Improperly connected, or faulty generator. Relay coil open or leads broken. Relay improperly adjusted. Chips on the permanent magnet.	Check connections and generator voltage and polarity. Replace coil. Readjust. Clean out chips.
Voltage relay will not open.	Broken or damaged return spring. Relay improperly adjusted. Chips on permanent magnet.	Replace spring. Readjust. Clean out chips.
Differential relay will not close but voltage relay closes.	Open coil or broken coil lead. Voltage relay contacts not touching. Chips on magnet. Improperly adjusted.	Replace coil. Clean and readjust voltage relay contacts. Clean out chips. Readjust.
Differential relay will not open.	Chips on magnet. Improperly adjusted.	Clean out chips. Readjust.
Contactor will not close but voltage relay and differential relay are closed.	Differential relay contacts do not touch. Coil open or leads broken. Excessive friction on moving core. Core rod bent.	Clean and readjust. Replace coil. Replace stationary core assembly. Replace core rod.
Contactor will not open but differential relay is open.	External short circuit between SW and APP terminals. Core rod bent. Contactor contacts out of adjustment.	Correct short circuit. Replace core rod. Readjust contacts.

of control is necessary when operating generators in parallel to equalize the voltage output for all loads.

PARALLEL OPERATION

In a parallel generator system, each generator will assume a share of the total load proportional to its voltage at the point of paralleling. The voltage regulators automatically assist each generator to assume its proper share of the total load by reducing the voltage of the generator carrying more than its share of the load and increasing the voltage of the generator carrying less than its share of the load. This is accomplished through the action of a load equalizer coil which is part of the regulator magnet coil assembly. (See fig. 10-12.) This coil and an equalizer potentiometer mounted on the base are used only for parallel generator installations.

Each equalizer coil in the system is connected between the equalizer bus and the negative brush of its respective generator. A voltage drop exists between ground and the negative brush of each generator. This drop is provided by load current flowing in the generator interpole and compensating windings or in an external resistance. When all generators are sharing the load equally, no current will flow through the equalizer coils.

If one generator carries more than its share of the load, the voltage drop in its negative line will be proportionally greater than the corresponding voltage drop for the other generators in the system. A second generator, connected in

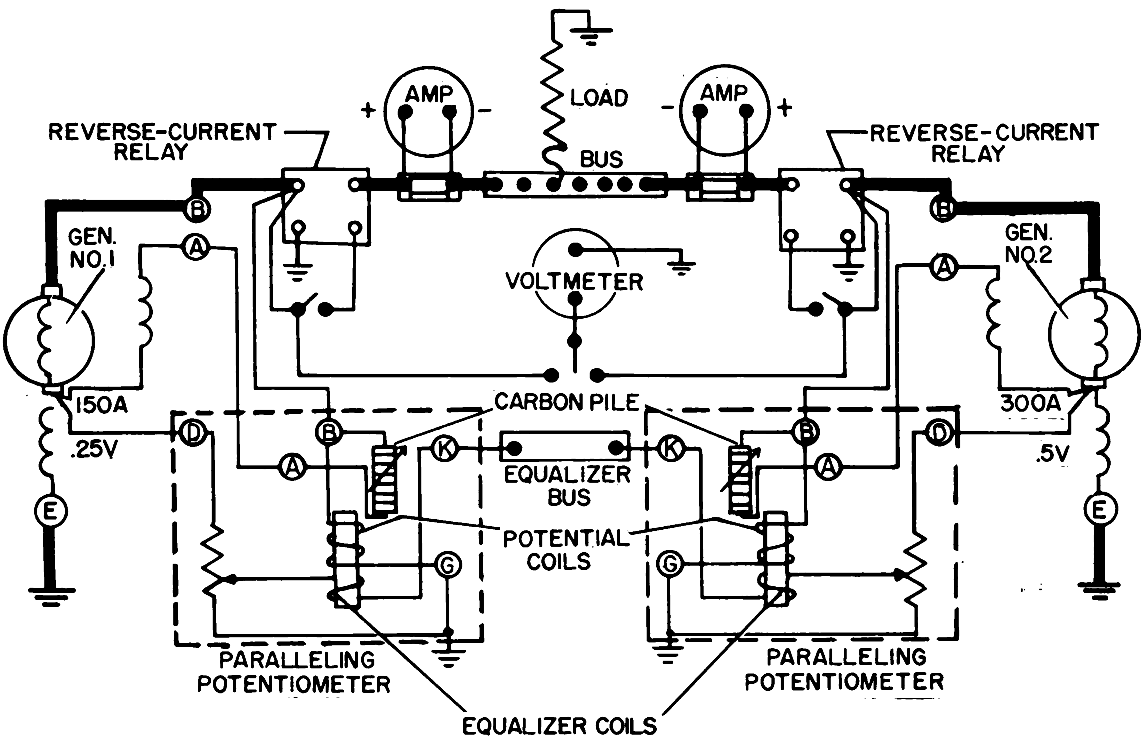


Figure 10-12.—Parallel generators using equalizer circuits.

parallel with the overloaded generator and carrying less than its share of the load, will have a voltage drop in its negative line proportionally lower than that of the first generator. Therefore, a difference of potential will exist between the two negative generator brushes.

Current then will flow from the negative brush of the higher output generator through the equalizer coil of the regulator connected to that generator, through the equalizer bus, through the equalizer coil of the regulator connected to the lower output generator, and finally to the negative brush of the lower output generator. Current flows from a more negative potential to a less negative potential through the equalizer bus.

As current flows from the higher output generator through its regulator equalizer coil, it follows a path from the D terminal to the K terminal. (See fig. 10-12.) The current flowing in this direction increases the magnetic attraction on the armature of the regulator and allows the diaphragm armature to decrease the pressure on the carbon pile. The pile resistance then will increase, thereby decreasing the field current and output voltage of the generator carrying more than its share of the load.

From the equalizer coil, the current passes through the equalizer bus and then through the equalizer coil of the voltage regulator connected to the generator which is carrying less than its share of the load. Through this coil, the current follows a path from the K terminal to the D terminals, or a path opposite to that followed in the first equalizer coil. Current flowing in this direction decreases the magnetic attraction on the armature of this regulator, allowing the armature diaphragm to increase the pressure on the carbon pile. The pile resistance then will decrease, thereby increasing the field current and output voltage of the generator which is carrying less than its share of the load. Thus the equalizing circuit has automatically helped the voltage regulators in lowering the voltage of the high generator, and raising the voltage of the low generator, so that the total load will be shared more equally by the generators.

Some means must be provided for opening the equalizer circuit of each generator in a parallel system since failure to open an equalizer circuit of a disconnected generator will result in lowering system voltage. An equalizer switch is frequently combined with the generator switch by using a suitable double-pole switch. For single generator systems, no equalizer connection need be made.

GENERATOR PARALLELING PROCEDURE

To simplify the paralleling adjustments, each voltage regulator in a parallel generator system should be adjusted to exactly the same no-load voltage. Allow all generators to run at or above minimum rated speed, if possible, for approximately one-half hour. This insures that the regulators are adjusted for parallel operation at normal operating temperatures.

If paralleling adjustments are made during flight, frequently observe the ammeter readings for all generators during operation prior to adjustment to prevent possible overloading of any one generator in the system. If the overloading occurs, a slight reduction of the voltage of that generator will correct the condition.

It is important that accurate ammeters be used for checking load current during the adjustment for proper parallel operation. To check for satisfactory ammeters, switch on one generator at a time while a constant load, approximately equal to the full-load rating of one generator, also is switched on. Compare the ammeter readings obtained as each generator supplies the load current. Satisfactory ammeters are indicated if all ammeter readings are equal. With all generator and equalizer switches closed and all generators operating at normal operating speed, switch on a load approximately equal to the full-load rating of any one generator in the parallel system. (All generators should be operated at the same speed for speed has some effect on parallel operation.)

Check the generator ammeters. Each generator should take its share of the load within plus or minus 10 percent of its rated output current. If such is not the case, proceed as follows: From the readings of the generator ammeters, determine which generator has the greatest error in the division of load current. Adjust the voltage regulator for that generator to increase or decrease the load current as required. In parallel generator systems, alternation of generator load should be made by adjusting the paralleling potentiometer located either on the shock mount or regulator assembly. Make all adjustments to the paralleling potentiometer one notch at a time. Move the control clockwise to increase the current taken by its generator and counterclockwise to decrease the current.

Continue paralleling adjustments until proper load division is obtained, always selecting for adjustment the generator having the greatest error in load division. If trouble is experienced in paralleling the generators check all generator and regulator connections, especially those in the equalizer circuit. Trouble may also be caused by improper regulator adjustment or a defective regulator.

Switch on as much load as possible up to the full load for each generator. The generator ammeters must indicate that each generator is taking its share of the load within plus or minus 10 percent of its rated output current. However, it is permissible for load division to be within plus or minus 15 percent of rated generator current. If not, adjust the current carried by the generator which has the greatest error in the division of the load to increase or decrease the current as required.

If adjustments to the paralleling potentiometers have been made to obtain proper paralleling, connect a portable voltmeter, having a range of 0 to 30 volts, to the positive and negative (or ground) buses and check the output voltage. If the output voltage is not 27.7 volts, turn the voltage regulating rheostats on the regulators of every generator in the parallel system, one notch at a time (clockwise to increase the voltage and counterclockwise to decrease the voltage) until the prescribed output voltage is reached.

Switch on maximum load up to full load per generator and check all generator ammeters. If the generators do not divide the load within proper limits, repeat the entire procedure outlined above. Do not alter the position of the pile adjusting screw or core. Adjustments to these parts must not be attempted with the unit installed in the aircraft.

CHAPTER 11

A-C GENERATOR REGULATION

This chapter deals with methods of regulating the output voltage of a-c generators. To understand these methods of regulation, the AE must first be familiar with the principles of operation of a-c generators. These principles and the methods of calculating for such factors as induced voltage, power, and speed are covered in Basic Electricity, NavPers 10086-A. Since the main purpose of this chapter is to cover a-c generators from the standpoint of regulation, generation is not given thorough coverage. However, a brief review of a-c generators follows.

ALTERNATING-CURRENT GENERATORS

The Navy uses many types of a-c generators for aircraft electric power. These generators range in size from the relatively tiny tachometer instrument generator to the 60,000 volt-ampere machines used on huge multiengine aircraft. Regardless of weight, shape, or rating, practically all of these generators have certain characteristics in common. The most common of these are as follows:

1. The a-c output is taken from a set of stationary windings (stator).
2. The a-c generator field (rotor) is a rotating magnetic field with fixed polarity.
3. Where voltage control is used, it is accomplished by controlling the strength of the rotating magnetic field.
4. The frequency of the output voltage is controlled by controlling the speed of rotation of the rotating magnetic field.

Figure 11-1 shows a simplified pictorial diagram of a single-phase a-c generator; however, it does not resemble an aircraft generator as to actual appearance. Figure 11-2 shows a typical a-c generator as it actually appears when separated into its major assemblies. Compare these two figures. Figure 11-1 will be used for reference in the explanation of basic a-c generator voltage control.

Any rotary generator requires a prime moving force, (1, fig. 11-1) to rotate the a-c field and exciter armature. This rotary force is transmitted to the generator through the rotor drive shaft and is usually furnished by a combustion engine, air or gas turbine, or electric motor. The exciter shunt field (2) creates an area of intense magnetic flux between its poles. When the exciter armature (3) is rotated in the exciter field flux, voltage is induced into the exciter armature windings. The exciter unit is nothing more than an ordinary d-c generator. The exciter output commutator and brushes (4) connect the exciter output directly to the a-c generator field input sliprings and brushes (5). Since these sliprings, rather than a commutator, are used to supply current through the a-c generator field (6), current will always flow in one direction only through these windings. Thus, a fixed polarity magnetic field is maintained at all times in the a-c generator field windings. When the a-c generator field is rotated, its magnetic flux is passed through and across the a-c generator armature windings (7). Remember, a voltage is induced into a conductor if it is stationary and a magnetic field is passed across the conductor, the same as if the field is stationary and the conductor is moved.

BRUSHLESS GENERATOR

A modern concept in the generation of a-c voltage is being utilized in current aircraft. This concept eliminates the need for brushes in the a-c generator. Figure 11-3 is a sectional schematic of the brushless a-c generator. The generator consists of a pilot exciter, an exciter, and the main generator. Utilizing an integral exciter with a rotating armature that has its a-c output rectified for the main d-c field, which

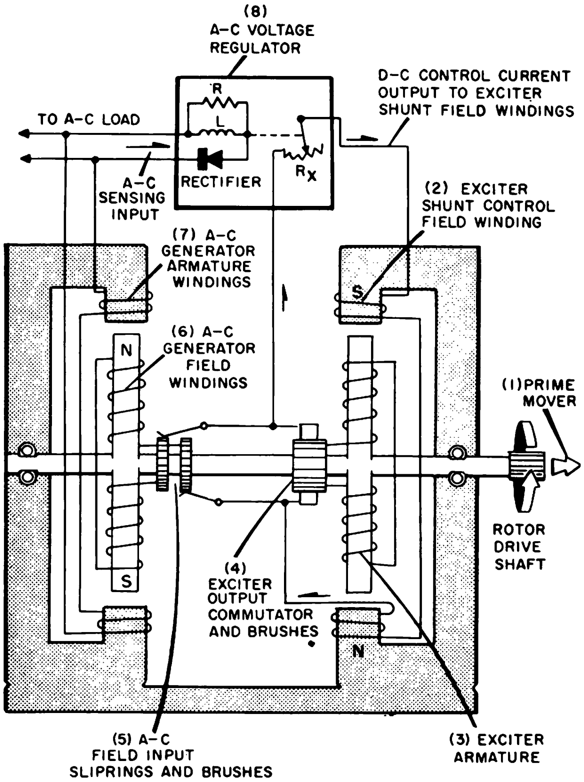


Figure 11-1.—Simplified a-c generator.

is also rotating, eliminates the necessity of brushes. The pilot exciter is an eight-pole, a-c generator.

The pilot exciter field is mounted on the main generator rotor shaft and is connected in series with the main generator field. The pilot exciter armature is mounted on the main generator stator. The a-c output of the pilot exciter is supplied to the voltage regulator, where it is rectified and controlled, and is then impressed on the exciter field winding to furnish excitation for the generator. The exciter is a small a-c generator with its field mounted on the main generator stator and its 3-phase armature mounted on the generator rotor shaft. Included in the exciter field are permanent magnets mounted on the main generator stator between the exciter poles. The exciter field resistance is temperature compensated by a thermistor. This aids regulation by keeping a nearly constant resistance at the regulator output terminals. The exciter output is rectified and impressed on the main generator field and pilot exciter field.

Rectification of the exciter output is accomplished by utilizing a 3-phase, full-wave bridge rectifier consisting of six high-temperature silicon rectifiers mounted in the rotor shaft of the main generator. The exciter stator has a stabilizing field which is used to improve stability and to prevent voltage regulator overcorrections for changes in generator output voltage. The generator is 3-phase, 4-wire, wye-connected with grounded neutrals. By using an integral a-c exciter, the necessity for brushes within the generator has been removed. The a-c output of the rotating exciter armature is fed directly into the 3-phase, full-wave rectifier bridge located inside the rotor shaft. The d-c output from the rectifier bridge is fed to the main a-c generator rotating field. Voltage regulation is accomplished by varying the strength of the a-c exciter stationary fields. Polarity reversals of the a-c generator are eliminated and the minimization of radio noise is accomplished by the absence of brushes.

PRINCIPLES OF A-C VOLTAGE CONTROL

In an a-c generator an alternating voltage is induced into the armature windings when magnetic fields of alternating polarity are passed across these windings. The amount of voltage induced into the a-c generator windings depends mainly on three things: the number of turns of conductor per winding, the speed at which the magnetic field passes across the winding (generator rpm), and the strength of the magnetic field. Any of these three could conceivably be used to control the amount of voltage induced into the a-c generator windings.

The number of windings is determined when the generator is manufactured. Also, if the frequency of a generator's output is required to be of a constant value, then the speed of the rotating field must be held constant. This prevents the use of the generator rpm as a means of controlling the voltage output. Thus, the only practical remaining method for obtaining voltage control is to control the strength of the rotating magnetic field. In some specialized applications, the field is furnished by a permanent magnet, such as that in tachometer generators. This type of a-c generator needs no voltage control. The simple generator in figure 11-1 uses an electromagnetic field rather than a permanent magnet type field. The strength of this electromagnetic field may be varied by changing the amount of current flowing

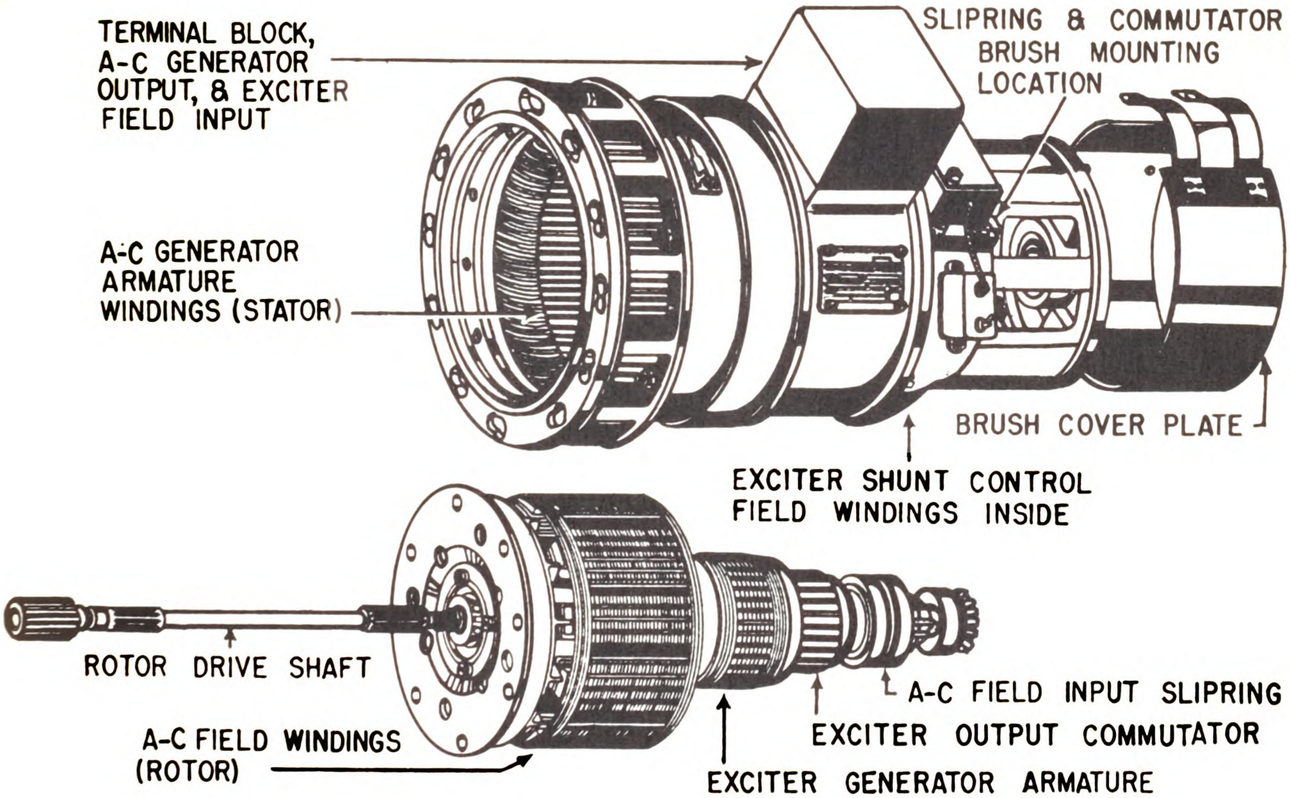


Figure 11-2.—Typical a-c generator.

through the coil. This is accomplished by varying the amount of voltage applied across the coil. By varying the d-c output voltage from the exciter armature, the a-c generator field strength is also varied. Thus, the magnitude of the generated a-c voltage depends directly on the

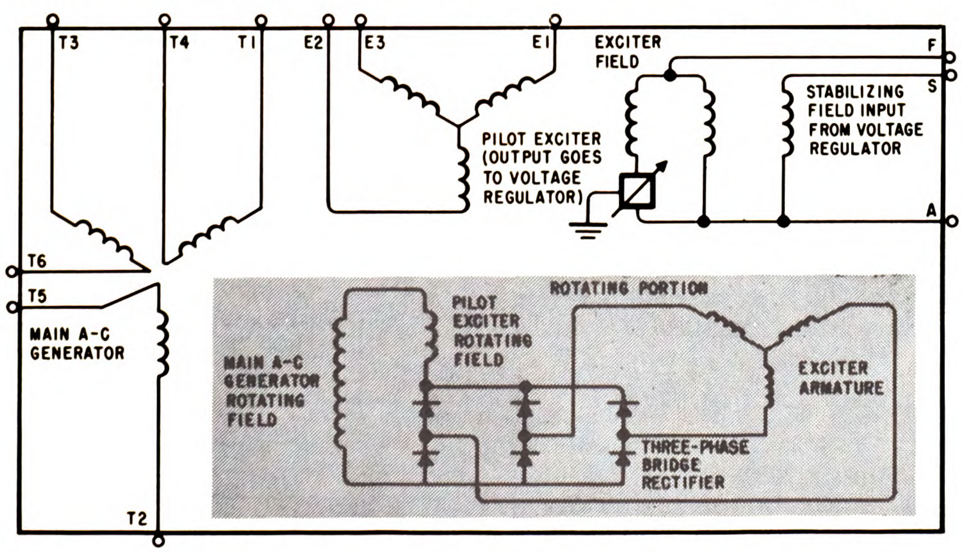


Figure 11-3.—Sectional schematic of a brushless a-c generator.

value of the exciter output. This relationship allows a relatively large a-c voltage to be controlled by a much smaller d-c voltage.

The next function of the a-c generator that the AE should understand is how the d-c exciter output voltage is controlled. Previously, it was discussed that voltage control in a d-c generator was obtained by varying the strength of the d-c generator shunt field. This is accomplished by using a carbon-pile voltage regulator. (Refer to chapter 10 of this training course for a review of this material.)

As already stated, the exciter of an a-c generator is essentially a d-c generator so the usual method of d-c generator voltage control may be used. A device which will vary the exciter shunt field current in accordance with changes in the a-c generator voltage is called an a-c generator voltage regulator. This regulator must also maintain a correct value of exciter shunt field current when no a-c voltage corrective action is required (steady state output). In figure 11-1, note that a pair of connections labeled a-c sensing input feed a portion of the a-c generator output voltage to the a-c voltage regulator (8). Note also that a portion of the exciter armature output is connected through the voltage regulator, then through both exciter shunt field windings, and finally back to the exciter armature. Obviously, the exciter supplies direct current to its own control field, in addition to the a-c generator field.

The essential function of the voltage regulator is to use the a-c output voltage as a sensing influence to control the amount of current the exciter may supply to its own control field. A drop in the output a-c voltage causes a rise in the exciter control field current. A rise in the output a-c voltage causes a drop in the exciter control field current. These latter two characteristics are caused by actions within the voltage regulator. These characteristics are common to resistive (carbon-pile) and magnetic types of a-c voltage regulators. All types of regulators perform the same functions, but accomplish them through different operating principles.

CARBON-PILE A-C VOLTAGE REGULATORS

PRINCIPLES OF OPERATION

The operating principles of a carbon-pile a-c voltage regulator are identical to those employed in the d-c type of regulator. That is, the strength of the magnetic field of a potential coil controls the compression of a carbon pile. The resistance of the carbon pile is thus controlled by the amount of voltage applied across the potential coil. In the d-c regulator, the potential coil is connected through a resistance directly to the d-c voltage to be controlled. The a-c regulator potential coil cannot be connected in such a direct manner because the alternating magnetic field would be practically useless for purposes of voltage regulation. This problem is solved by making a full-wave rectifier a part of the basic regulator.

Figure 11-4 is a simplified schematic of a single-phase a-c voltage regulator. Some of the a-c line voltage (a-c generator output) is connected across terminals B and G. In series with terminals B and G is a 500-ohm voltage-dropping variable resistor, a 150-ohm voltage adjusting potentiometer, and a rectifier. The potential coil is connected across the d-c terminals of the rectifier. Any change in a-c voltage results in a change in direct current through the coil, thus causing a change in carbon-pile compression. The same effects may be caused by moving the potentiometer setting. However, the most significant relation to understand is that any change in the a-c voltage applied across terminals B and G causes a corresponding change in resistance between terminals A and D (carbon-pile compression). Thus, by connecting the carbon-pile resistance in series with the exciter shunt control field, the current through that field is controlled indirectly by the value of line a-c voltage.

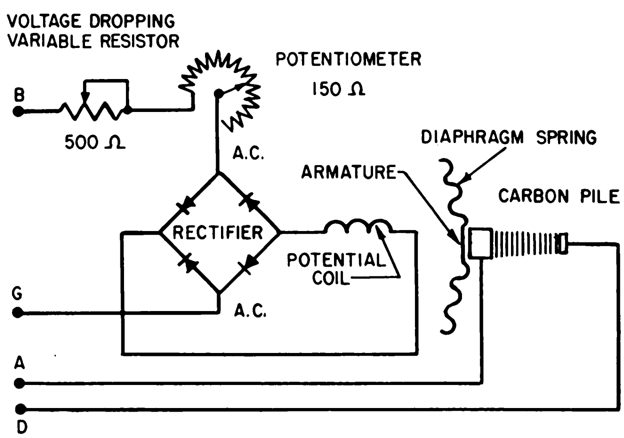


Figure 11-4.—Simplified schematic of a single-phase a-c voltage regulator

A simplified drawing of an a-c generator and its controlling regulator is shown in figure 11-5.

A complete sequence of what happens when a change occurs in the generator's a-c output is as follows: Assume that a heavy load has been placed on the a-c bus. The resultant decrease in voltage across terminals T1 and T2 causes a decrease in the voltage at terminals B and G on the voltage regulator. This same decrease in a-c voltage also occurs across the regulator rectifier; this causes a decrease of current through the potential coil. As the potential coil current decreases, the strength of its magnetic field also decreases. The resultant partial release of magnetic "pull" acting on the iron armature allows the diaphragm spring to press the iron armature slightly tighter against the carbon pile.

Increased pressure on the pile improves the quality of contact between the individual carbon washers which comprise the pile. The result is a decrease in resistance of the pile. When the pile resistance decreases, pile current increases.

This pile current flows from the exciter armature output brush through terminal F1, through the carbon pile, back through terminal F2, then through the exciter shunt control field, and finally returns to the exciter armature. When the pile current (exciter field current) increases, the exciter control field is made stronger and a greater voltage is induced into the exciter armature. The increased exciter output voltage causes an increased current through the a-c generator field. As the a-c generator field is made stronger, a greater a-c voltage is induced into the a-c armature windings. The a-c voltage, across terminals T1 and T2 is then raised back to the proper level. Should the load be decreased the regulator would react in a manner to keep the output constant.

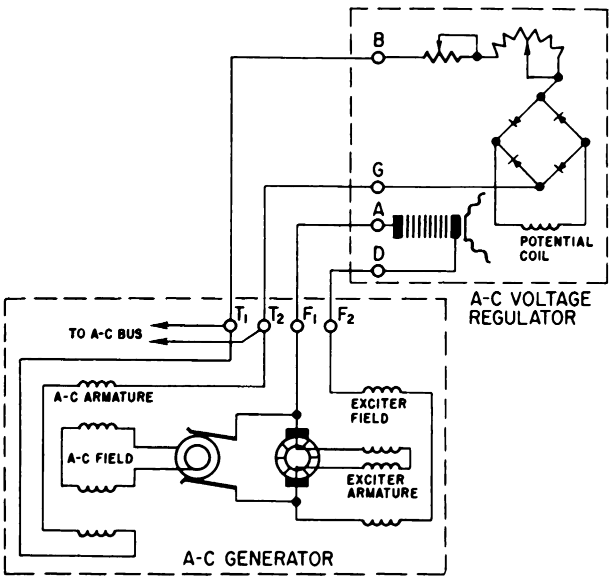


Figure 11-5.—A-c generator and regulator.

CONSTRUCTION

The details of construction and operation of carbon-pile d-c regulators, single-phase a-c regulators, and 3-phase a-c regulators are quite similar when comparing only the carbon-pile regulator element. On all three types of regulator assemblies, the carbon-pile regulator element is detachable from the mounting base (panel). Figure 10-2 in chapter 10 shows a carbon-pile element (13) of a d-c voltage regulator. It is so similar to the type of element that is used in a-c regulators that it is used for purposes of explaining a-c regulators.

Two important features of the a-c regulator which are shown in figure 10-2, are the magnet core (6) and pile adjusting screw (20). Note that both of these parts are threaded and mounted in such a way that they may be turned in or out of the regulator element. The magnet core is commonly referred to as the "core screw." When the core screw is turned in or out, the space between its inner end and the diaphragm armature assembly (10) is changed. Turning the core in moves it closer to the iron armature and the core's magnetic pull acting on the armature is stronger. When the core is turned out, its magnetic pull on the armature is decreased. It can be seen that by turning the core screw in or out, the change of pull which acts on the armature will cause changes in carbon-pile compression. The pile adjusting screw (20) bears directly against the carbon pile through the outer contact plug (19).

Carbon-pile compression can also be changed by turning the pile screw in or out. It is important to note that three methods have been described for controlling the all-important carbon-pile compression: The adjusting potentiometer (rheostat (31)) which controls current through the magnet coil (3), the positioning of the magnet core screw, and the positioning of the pile adjusting screw. It is important to understand how

each of these three methods affect the operation of the voltage regulator. Each of the three methods is used to do a definite job. The core screw and pile screw are used only during test bench adjustment. This adjustment is performed in the shop by using the generator testing assembly. (See fig. 7-13 and 7-14.) The voltage adjusting potentiometer is used after the regulator has been bench tested and reinstalled on the aircraft. This potentiometer adjustment is necessary because there will be slight differences in the test bench power system and the aircraft power system.

The core screw and pile screw are always included in the carbon-pile regulator. However, associated parts such as the potentiometer and rectifier may sometimes be mounted on the base assembly. For instance, in figure 11-6 the potentiometer and rectifier are mounted on the carbon-pile regulator, but in figure 11-7 the rheostat (6) and rectifier (4) are mounted on the base panel structure (1).

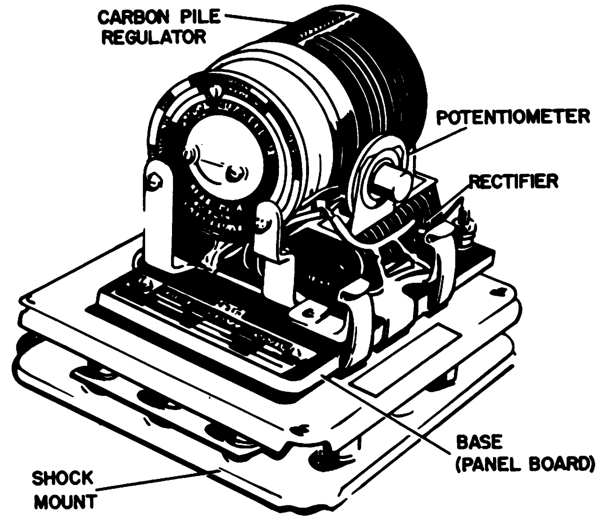
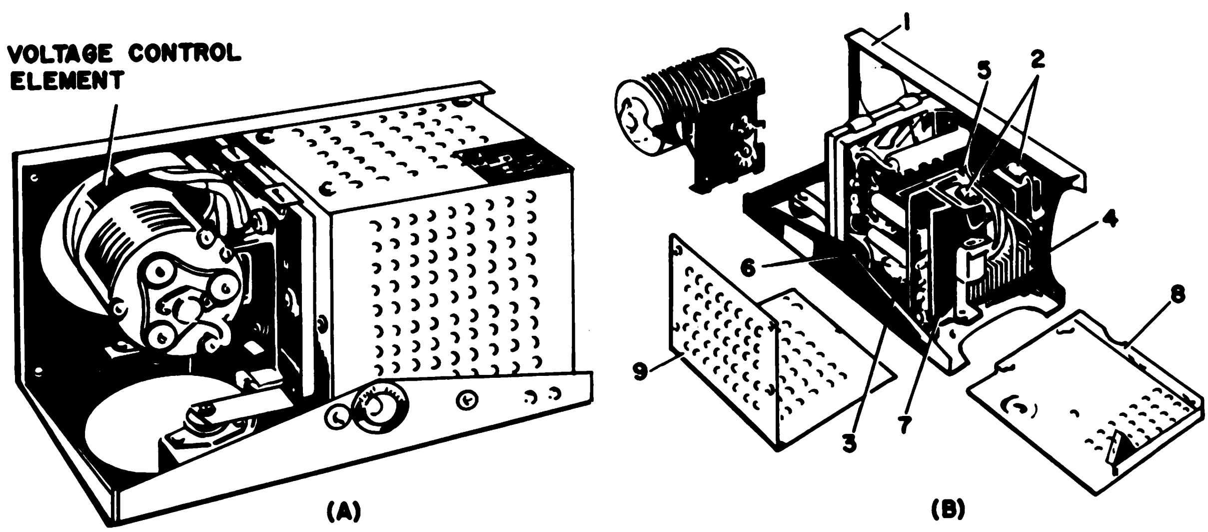


Figure 11-6.—Single-phase a-c voltage regulator.

The entire regulator assembly must be used when making bench tests and adjustments. The construction of the carbon-pile element is essentially the same for both single-phase and 3-phase regulators. However, the associated equipment for a 3-phase regulator is more complex than for a single-phase regulator. Figure 11-8 is an electrical schematic for the entire 3-phase a-c regulator assembly shown in figure 11-7.



1. Base panel structure.
2. Line transformers.
3. Mutual reactor.
4. Rectifier.
5. Damping transformer.
6. Voltage adjusting rheostat.
7. Terminal board.
8. End cover.
9. Top cover.

Figure 11-7.—Three-phase a-c voltage regulator.

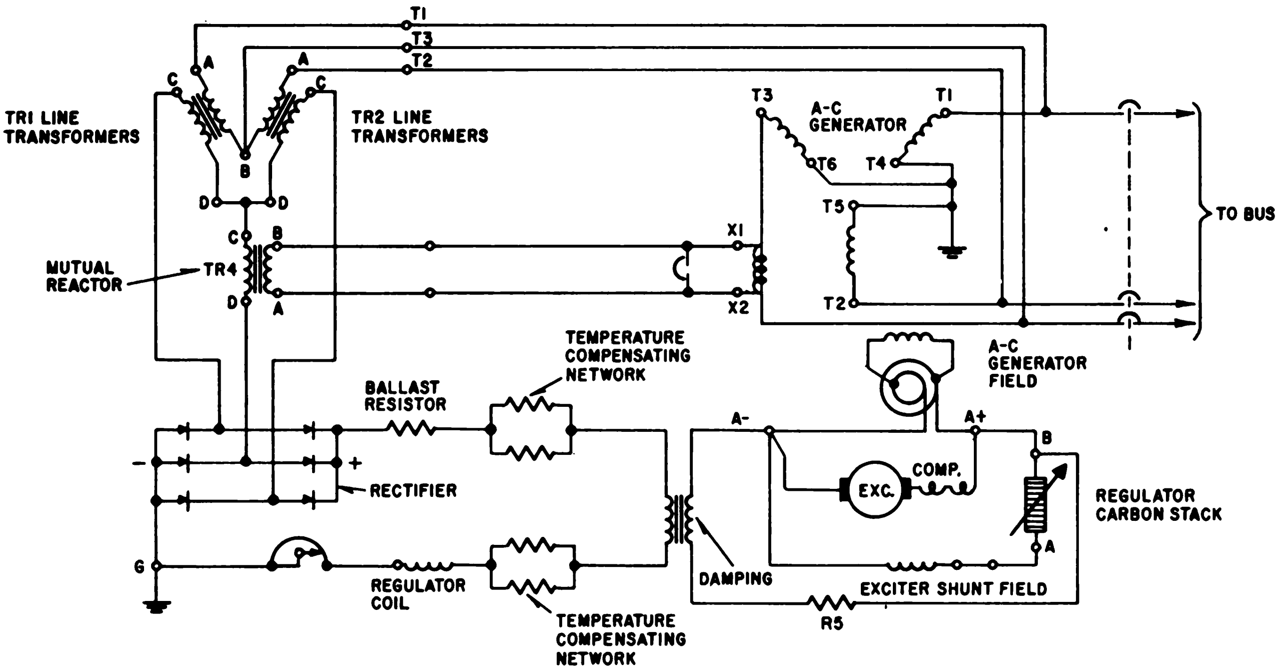


Figure 11-8.—Schematic diagram of 3-phase a-c voltage regulator.

In figure 11-8, three a-c voltage sensing connections are made from the a-c generator output terminals T1, T2, and T3 to the primary windings on the line transformer. Both primary and secondary windings of the line transformer are connected open delta. The secondary output, which is still 3-phase, is connected to the 3-phase full-wave rectifier.

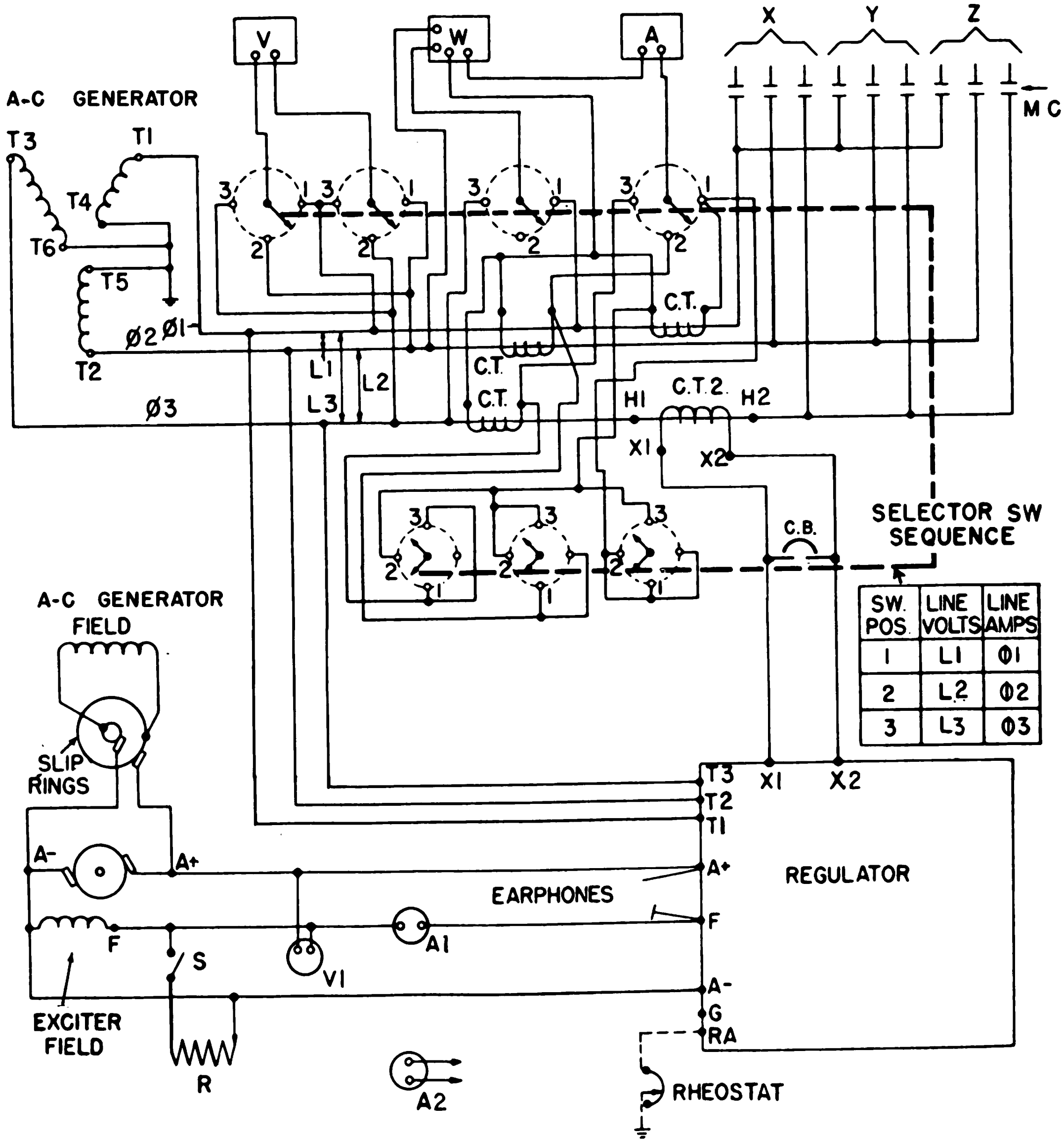
The d-c output voltage of the rectifier is an average of all 3-phase voltages. Connected in series with the d-c rectifier output are ballasting and temperature compensating resistors, the secondary of a damping transformer, the regulator coil, and an adjusting rheostat. In the single-phase regulator, the adjusting rheostat is in the a-c half of the rectifier. In the 3-phase regulator, the adjusting rheostat is in the d-c portion (regulator coil). In both cases, however, the adjusting rheostat's purpose is the same. The damping transformer acts to smooth out transient pulsations in the exciter or a-c generator outputs. The mutual reactor windings are used for load balancing when the a-c regulator is operated in parallel with another regulator.

ADJUSTMENT

Bench Adjustment

The detailed procedures for adjusting a 3-phase regulator are given—these procedures include the steps to be taken when adjusting a single-phase regulator. Because of the similarity of adjusting the two types of a-c regulators, only one is explained. For a detailed explanation of how to adjust a particular regulator consult the manuals for the regulator, as well as the manuals of the test assembly being used. Instructions for adjusting specific types of a-c voltage regulators are given in Aircraft Electrical Power Equipment, NW 17-15BA-500.

The circuit shown in figure 11-9 is used in the explanation of a-c voltage regulator adjustment. This shows the necessary connections and switching procedure for testing 3-phase sensing a-c voltage regulators operated in conjunction with an associated a-c generator mounted on a variable speed generator drive stand and supplying power to variable loads. (NOTE: Refer to figure 7-13 and 7-14 in chapter 7 of this course for pictures of a test stand and test assembly that are used in adjusting regulators.)



SW. POS.	LINE VOLTS	LINE AMPS
1	L1	Φ1
2	L2	Φ2
3	L3	Φ3

Figure 11-9.—Voltage test circuit showing equipment required to adequately adjust and test regulator assembly.

Nomenclature for Figure 11-9

A—Ammeter (0-5 ampere scale) for reading line current.
A1—Ammeter (0-10 amperes d-c) for reading stack current.
A2—Ammeter (0-300 milliamperes d-c). To read regulator coil current, insert ammeter prods (separated by a thin insulation sheet), between base pin C (not shown) and the associated contact blade.
A- —Exciter terminal.
A+ —Exciter terminal.
C.B.—Circuit breaker or shorting switch for keeping the transformer C.T.2 off the line when not needed.
C.T.—Current transformer (100/5 ratio) for metering circuit.
Earphones—Standard earphones with a 1-microfarad capacitor.
F—Exciter terminal.
H1—Terminal of transformer C.T.2.
H2—Terminal of transformer C.T.2.
L1 through L3—Line voltages.
M.C.—Magnetic contactors pushbutton control.
R—Adjustable resistor for measuring minimum resistance.
Rheostat—125-ohm, 5-ampere variable resistor.
SELECTOR SW—A 3-position multisection selector switch, two sections for reading line volts, one for applying wattmeter voltage, one for reading line current as well as applying wattmeter current and three for shorting meter current transformers. Shorting switches must be physically arranged to apply the short before the meter is removed.
S—Switch to be closed only for minimum resistance test.
T1 through T6—Generator terminals.
V—Voltmeter (0-300 volts a-c scale) for reading line voltage.
V1—Voltmeter (0-15 volts d-c) for reading stack voltage.
W—Wattmeter (0-5 ampere, 0-300 volts a-c) for reading power by the 2-meter method. Scale reading x scale ratio x meter current transformer ratio = watts.
X—Delta-connected fixed resistance load.
Y—Wye-connected variable resistance load.
Z—Variable reactive load.
ϕ1 through ϕ3—Output phases.

After the regulator is placed in a test circuit (fig. 11-9), check the generator connections before starting the generator drive stand to make sure the phase sequence is T1, T2, and T3. Turn the regulator voltage adjusting rheostat to the left (counterclockwise) to give minimum voltage. Start the drive stand, adjust the speed to the nominal rating of the generator, and close the exciter field circuit. Check the polarity of the voltage on the carbon-pile regulating element coil.

Turn the stack adjusting screw clockwise to bring the a-c line voltage meter V up to approximately 200 volts. Run the unit 10 to 15 minutes, watching closely for signs of overheating or smoke from any of the regulator components.

CARBON-PILE ELEMENT.—With the generator drive test stand operating at rated generator speed, the exciter field switch closed, and the variable resistor set at the mechanical midpoint, turn the stack adjusting screw counterclockwise until the voltage drops to 162 volts on meter V. This is point p on the adjustment curve of figure 11-10. Refer to this curve in connection with the explanation that follows.

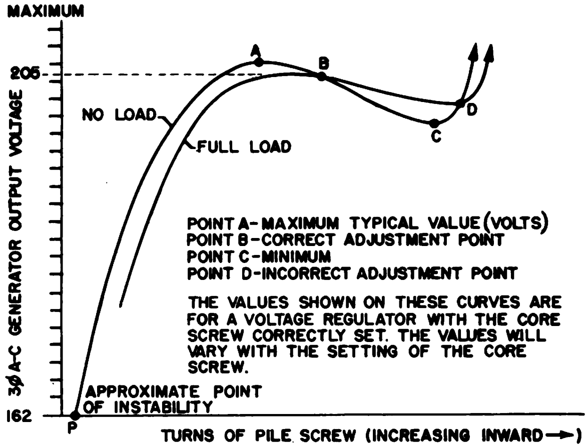


Figure 11-10.—Typical adjustment curve.

Turn the stack adjusting screw clockwise; the line voltage will begin to rise. Continue turning the adjusting screw clockwise until the line voltage (meter V) goes through a peak at point A and then falls approximately 4.2 volts. This is approximately point B on the adjustment curve. Point B is the proper regulating point. After this point has been reached continue turning the pile screw clockwise until point C is reached. Record the voltage at point C. To accurately determine point C, it is necessary to allow the voltage to rise slightly toward point D. Stop turning the adjustment screw inward as soon as the voltage begins to increase.

If, after turning the pile adjustment screw clockwise as far as it will go, the voltage does not drop to point C, the carbon disks have worn until the pile is too short. Shut down the test equipment. Remove the carbon disks, clean the insulation tube, and insert a new carbon pile. After a new pile is inserted, it is necessary to perform a complete readjustment.

Subtract the value recorded at point C from the value at point B. The difference must be at least 4.6 volts. If the difference is less than 4.6 volts, shut down the test equipment. Remove the regulator from the test stand and return the regulator to overhaul. If the difference is more than 4.6 volts, this indicates that the carbon disks are in workable condition, turn the pile screw outward (counterclockwise) until the voltage has returned to point B. Apply an 18 kva load. If the generator voltage drops when the load is applied, turn the pile screw in slightly (cw). If the voltage rises, turn the pile screw out (ccw). CAUTION: Turn the load off before each adjustment is made.

Thus, the pile screw is used to obtain a stable full load and no load voltage. If this stable voltage is above 205 volts, turn the core screw in (cw) slightly to obtain 205 volts. If the voltage is less than 205 volts, the core screw is turned out (ccw). It can be seen that the pile screw is used to obtain stability, and the core screw is used to obtain the actual value to which the a-c generator voltage is regulated. It may be necessary to adjust the pile and core screws several times during the bench setting procedure.

CREEP AND FRICTION TEST.—The creep test should follow immediately after the adjustment with no change in test setup. Close the load switch and apply full load for 3 minutes. Remove the load and record the average line voltage shown on voltemeter V, no load. Apply full balanced load, holding the drive stand speed at nominal rated speed of the generator. Read and record the line voltage every 30 seconds for 5 minutes. Remove the load and take immediate readings of the line voltage and record the readings. Read and record the line voltage every 30 seconds for 5 minutes. The line voltage must not deviate outside the limits of 199 to 211 volts. If the line voltage drops below the lower limit during this test, check to see if the exciter is limiting the line voltage. If the stack resistance drops below 1.5 ohms, it indicates the exciter is overheated or defective. If the creep is excessive, try

resetting the stack screws a few degrees on either side of the first adjustment and rerun the creep test. If the adjustment does not help, the armature assembly must be replaced. To avoid error by slight load unbalance, read all three line voltages and record the average. If the load is balanced correctly, this will not be necessary.

The friction test will follow the creep test with no change in test setup. Tap the stack housing lightly, watching the voltmeter V as this is done. The voltage will change approximately 2.5 volts or less. This change is an indication of friction. If the friction is excessive, use the same corrective measures as mentioned for creep. Any improvement in either creep or friction will improve the other.

CHANGING LOAD.—Adjust the line voltage to 205 volts at the nominal rated speed of the generator; the regulator should be warm for this operation. Set the generator speed at minimum rated speed. Record the line voltage at no load. In steps, apply the 50 percent balanced load, 100 percent balanced load, and 150 percent balanced load. Read and record the line voltage at each step. Now reduce the load to 100 percent load, then to 50 percent load, and then to zero load, reading and recording the line voltages at each step. Note that the load is to be increased and reduced in steps. Do not remove the load and then apply the next load. During this test the line voltage must not deviate outside the limits of 199 to 211 volts (± 6 volts from the initial no load setting of 205 volts). If the line voltage goes outside the limits, overhaul is necessary.

SPEED REGULATION.—This test should follow immediately after the test for voltage regulation with changing load. The line voltage should again be adjusted to 205 volts. With no load on the generator, vary the speed of the drive stand from the minimum rated speed of the generator to the maximum rated speed, taking readings at the three points of minimum, nominal and maximum rated speed. Again the voltage must not deviate outside the limits of 199 to 211 volts. If the "dip" is correct and the stack screw adjusted correctly, no deviation should be experienced, during the speed regulation test. Should difficulty be experienced, the unit should be overhauled.

STABILITY.—This test should follow immediately with no change in test setup. With the generator speed at maximum rated speed, apply and remove full balanced load, listening intently to the earphones. Note that the application and removal of the load should not cause more than three or four clicks in the earphones. A steady hum is merely an indication of commutation noise. The two noises are not easily confused. If the regulator is unstable, have the stack carefully cleaned. To assist in cleaning the carbon disks, rub them gently together while they are on the disassembly rod. At the same time make a careful check for alinement of parts and squareness of surfaces. If an end contact disk is burned only at one spot, it is evident that a surface is not square. A burned surface is the last to break contact and is a high spot. As a general rule, correct the squareness and consequently the instability at the burned spots. If this does not correct the instability, check for hunting. This hunting will usually be of a low-frequency nature and instability of a high-frequency nature.

REACTIVE LOAD.—Continue with the setup as for the previous test but adjust the generator speed to nominal rated speed. Prepare the reactive load bank to give a balanced load of 50 percent of full rated current at 0.75 power factor lagging and at 205 volts on the line. Note that the line voltage should be set with the current transformer C.T.2 in the circuit. Read and record all three lines voltages at no load and compute the average. With the current transformer in the circuit, apply the reactive load.

Read and record all line voltages and compute the average. This average voltage with the reactive load must be between 190.7 and 194.8 volts. Repeat this test using the same load current, unity power factor, with the current transformer in the circuit. Read the voltages as before and record. This last test must not show a drop or rise in the line voltages greater than 2 volts. If the voltage rises with the reactive load, either the current transformer on the internal mutual reactor is improperly connected or the phase rotation is reversed. Check carefully to determine the reason for improper operation. If the units are correctly installed, no excessive drop or rise is experienced.

MINIMUM RESISTANCE TEST.—With the generator at nominal rated speed and no load, close the series switch S (fig. 11-9) and adjust the variable resistance connected across the F and A- terminals of the generator until the regulated voltage drops to 194.8 volts. The stack ammeter A1 should read at least 5 amperes. Read the stack voltage, voltmeter V1, and the current, ammeter A2, and compute the stack resistance by dividing the volts by the amperes. This resistance must not be greater than 0.9 ohms. If the resistance is too high, it may be

caused by a small dip, a high-resistance stack, or a dirty stack.

HUNTING.—Hunting is identified by an appreciable fluctuation of the voltmeter needle. During any of the previous tests, if the voltmeter needle vibrates excessively, it may be caused by any of four reasons: exciter polarity reversed, one winding of the damping transformer reversed, damping transformer windings interchanged, and damping transformer primary or resistor R5 may be open. (See fig. 11-8.)

Installation Testing

The operation of the regulator assembly is completely automatic after it is properly installed in the system. However, when a new or newly regulated unit is installed in an aircraft the following installation test should be made. NOTE: Operation of the a-c regulator with an a-c/d-c generator is dependent on the proper functioning of the d-c system. Therefore, it is recommended that the operation of the d-c regulator be checked before checking the operation of the a-c regulator.

Perform all regulator checking operations with the generator operating at, or above, minimum rated speed. Observe the engine manufacturer's instructions carefully to prevent overheating when operating the engine on the ground. As soon as the checking procedure is completed, the engine should be throttled down.

The following procedure should be followed when checking the regulator for stability:

1. Switch off all load.
2. Connect the leads from a pair of high-impedance earphones, having a 2-microfarad capacitor in series with one lead, across the carbon-pile terminals.
3. Gradually accelerate the engine to the maximum allowable groundspeed and listen carefully in the earphones. If a succession of popping noises indicating instability is heard, replace the regulator. If instability is still encountered, carefully check the generating system for possible causes of the unstable condition.
4. A smooth steady hum or roaring noise in the earphones indicates a stable regulator. A rapid succession of clicking or popping noises in the regulator indicates an unstable regulator. Since instability of any kind causes permanent damage to the carbon disks, remove the regulator for repair if even faint continuous clicking or popping noises are heard in the earphones.
5. Switch on as much load as possible up to the full load rating of the generator; then switch off the load. Repeat this procedure several times. The regulator must remain stable. If noises in the earphones indicate an unstable regulator, remove the unit for repair. NOTE: Instability must not be confused with the click heard in the earphones each time a load is applied or removed from the generator, since this will occur even with a stable regulator.

The following procedure should be followed when performing a voltage check on the regulator:

1. Connect the leads of an accurate a-c portable voltmeter to the a-c output A and a-c output B terminal screws on the panel board. The accuracy of this test depends upon the accuracy of the voltmeter used, so be certain to use the proper meter.
2. Accelerate the engine until the a-c generator is operating at or above its minimum rated speed as given in the manual covering the a-c generator being used. The lowest permissible engine speed can be calculated from the ratio of generator drive speed to engine crankshaft speed given in the engine manufacturer's manual. To determine this speed, divide the minimum rated a-c generator speed by the ratio of generator speed to engine crankshaft speed. Most generators operate at or above minimum rated speed if the engine is run at 1,800 rpm.
3. Switch on maximum a-c load up to the full a-c load rating of the generator. The full load a-c voltage as indicated on the voltmeter should be 117 volts.
4. If necessary, adjust the a-c output voltage as closely as possible to 117 volts by turning the potentiometer. If the adjustment required is in excess of 3 volts, or if the a-c output fluctuates, replace the regulator. Do not make any adjustment to the pile adjusting screw, the magnet core, or the resistor slider, since this will change the voltage setting and regulating characteristics of the unit.
5. Switch off all a-c load. The no load a-c output voltage, as read on the voltmeter, should remain constant or rise slightly as load is switched off, however, remaining between 114 and 120 volts. Should the voltage rise above 120 volts or fall below 114 volts as load is switched off, replace the regulator.

Upon completion of the stability and voltage checks, operate the generator at or above

minimum rated speed for 10 to 15 minutes, if possible, in order to warm up the regulator. Repeat the stability and voltage checks. The output voltage should remain between 114 and 120 volts. If warmup on the ground is impossible, the checks should be performed after the regulator has warmed up on flight or while the regulator is still hot at the conclusion of a flight.

Maintenance Testing

Your work in connection with regulator maintenance requires periodic inspections to determine the operating condition of the regulator. Stability and voltage checks, as just described, must be made. Visual inspections require that you remove the regulator from the panel. Before removing the regulator make sure that the generator is at rest or that its field circuit is open. Failure to observe this precaution will result in pitted or burned contact surfaces.

After removing the unit, wipe all terminal and spring contact surfaces clean with a dry cloth. If any corrosion or pitting is observed, the regulator should be replaced. Check the regulator visually for a cracked and excessively corroded base; loose lead connections; cracked or burned rectifier, potentiometer, or resistor; cracked or broken insulation; or a broken or cracked housing. If defects are found, the unit must be repaired or replaced.

Make sure that all bolts used to secure the unit to the aircraft structure are tight. Inspect all external wiring connected to the unit. Replace broken leads or leads having worn, cracked, or burned insulation. Replace broken terminals and terminal lugs, and resolder or tighten loose connections. If shielded cable is used, be sure that the screw fitting is tight.

In all cases of failure and improper regulator operation, investigate the trouble at the earliest opportunity to prevent further damage to the unit. Do not attempt to operate a regulator which is not functioning properly.

Periodically the regulator must be removed from the aircraft for overhaul. The overhaul procedures constitute a complete disassembly of the unit and involve the use of special test equipment available only at an overhaul base.

The depth of maintenance that you may perform on regulators will be determined by the activity to which you are assigned. Electronic Material Bulletin No. 5-56 prescribes the depth of maintenance that may be performed on aircraft generators, regulators, and inverters by various activities. Should a question arise as to whether you are supposed to perform a certain operation, refer to this bulletin for clarification.

MAGNETIC AMPLIFIER REGULATORS

A somewhat recent addition to the equipment which the AE is required to understand and maintain is the magnetic amplifier type regulator, sometimes referred to as the static a-c voltage regulator. As the word static indicates, there are no moving mechanical parts in the entire regulating mechanism (except for exciter control relays which operate only once, when initial generator voltage is built up).

Figure 11-11 shows a magnetic amplifier regulator, with its cover open, used in many current aircraft.

The overall operating principles of magnetic amplifier regulators are as follows. In accordance with the control exerted by the regulator, a certain amount of power is fed to the exciter's control field. The amount of power fed to the field is regulated by saturable reactors. (Saturable reactors are discussed in Basic Electricity, NavPers 10086-A, chapter 18, under the heading "Magnetic Amplifiers.") The output of the saturable reactor is fed to the exciter field. However, the direction and magnitude of d.c. in the reactor's control windings control the operation of the magnetic amplifier. In turn, the magnitude and direction of control-winding current is determined by the magnitude and direction of imbalance of an ordinary d-c Wheatstone bridge. This bridge obtains its d-c power from rectifiers which are fed by the line a-c voltage to be regulated. Thus, the level of that line a-c voltage is ultimately responsible for the amount of d-c power fed to the exciter control field.

The regulator consists of a voltage reference circuit, a two-stage magnetic amplifier, and the associated power transformer and rectifier. The reference circuit consists of a 3-phase rectifier, an adjusting potentiometer P1, and a bridge circuit made up of two fixed resistors and two glow tubes. These units are shown in figure 11-12. Potentiometer P1 is adjusted so that at rated bus voltage there is a zero potential difference between A and B on the bridge. For any other input voltage, the voltage drop across the glow tubes causes a potential to exist between points A and B.

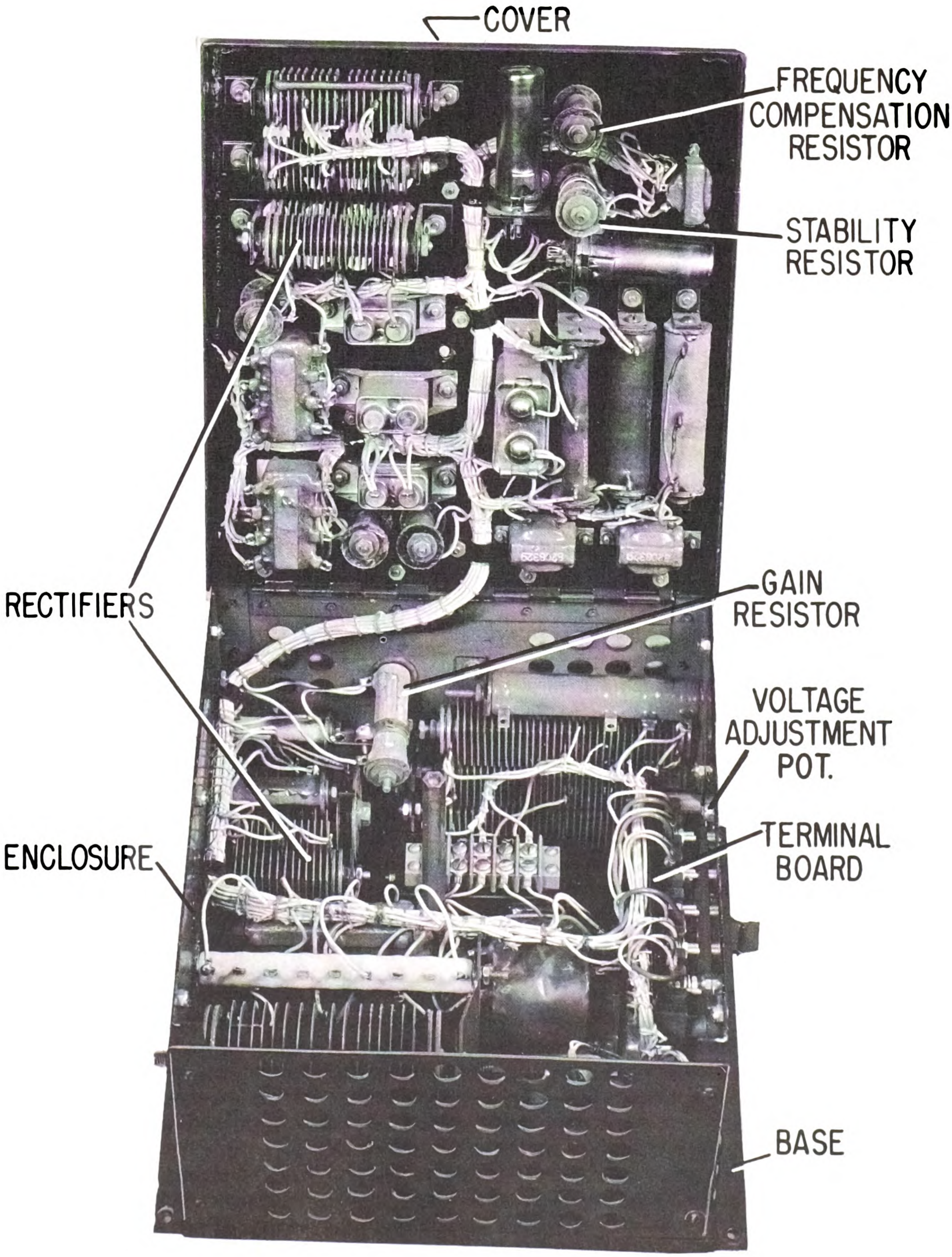


Figure 11-11.—Magnetic amplifier regulator.

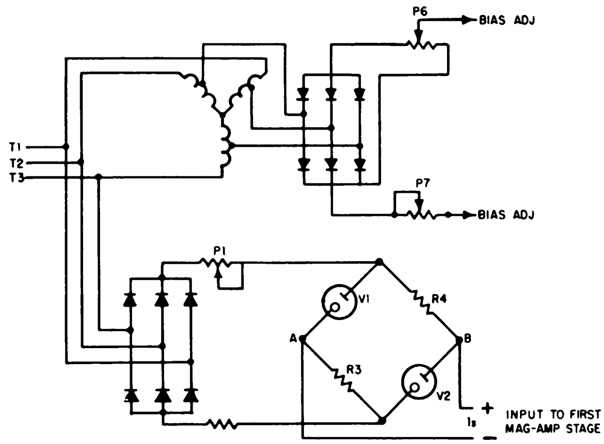


Figure 11-12.—Voltage reference circuit.

For example, if the generator voltage is low, the current flow through the arms of the bridge is reduced. The voltage across R4 is less than the fixed voltage across V1; consequently, point B is at a higher potential than point A. This gives an error signal used as an input to the first magnetic amplifier stage. For higher input voltages the error signal polarity is reversed.

The second unit in the system is the magnetic amplifier. The first stage magnetic amplifier, as shown schematically in figure 11-13, consists of two reactors, supply voltage transformers and rectifiers, and the following windings: reference, d-c bias, damper circuit, load circuit, and feedback circuit. The d-c bias winding fixes the operating level of the reactors and is adjusted by potentiometers P5 and P6.

Potentiometer P6 regulates the magnitude of the bias voltage, and P5 regulates the magnitude of biasing current on each reactor to

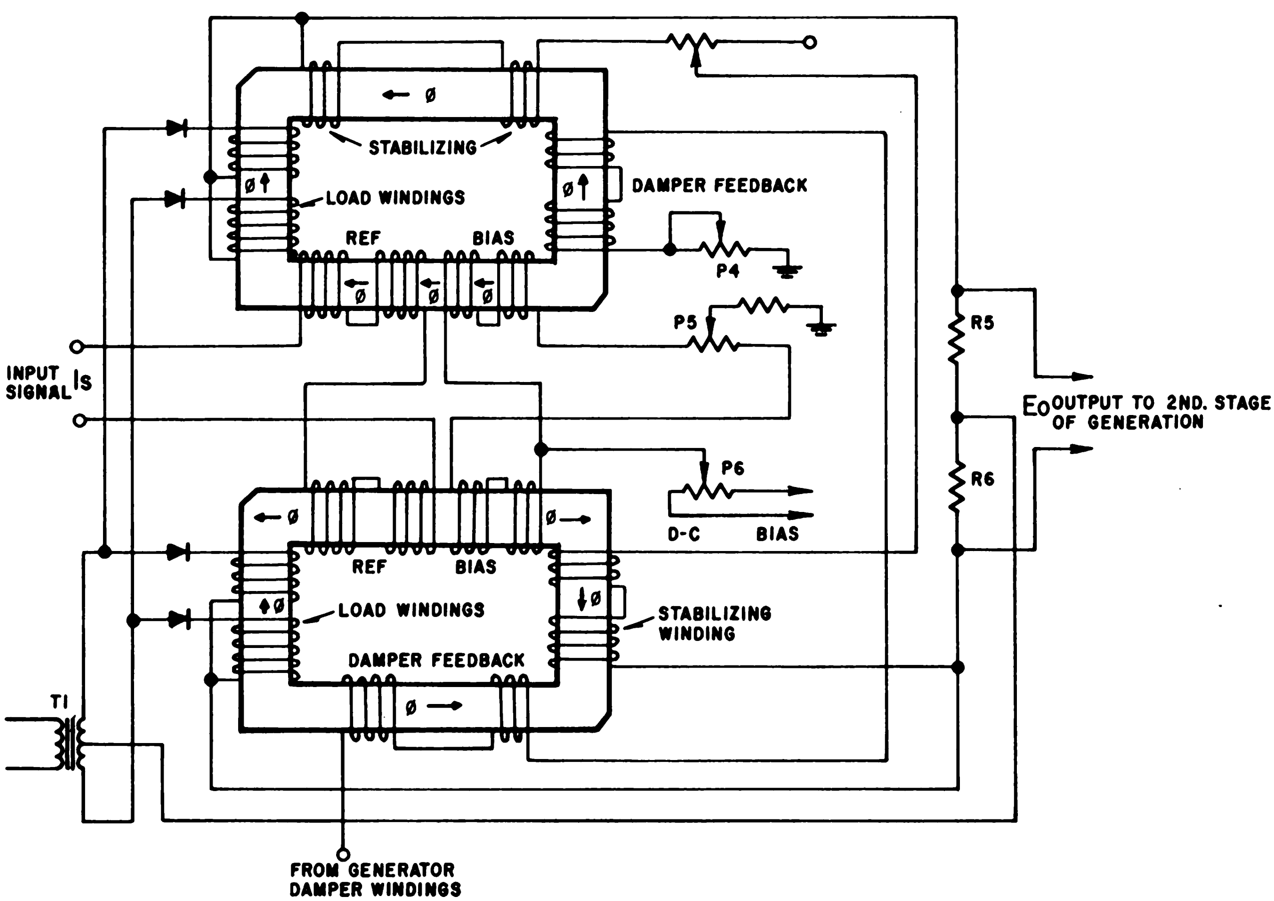


Figure 11-13.—First magnetic amplifier stage.

overcome the slight differences in the two cores and the associated rectifiers. If the bias voltage is properly adjusted and if a zero error signal input exists, the voltages developed across R5 and R6 are equal, and the output is zero.

The damper circuit is connected into the circuit and is used as a stabilizing winding. Its source of power is the damper winding of the generator. The generator damper winding is energized through transformer action by a changing generator excitation current, and is therefore proportional to the rate of change of excitation. This current is used as a feedback signal in the first magnetic amplifier stage because its polarity is always such that it opposes the error signal input.

The magnitude of the damper feedback current is adjusted with potentiometer P4. Its function is to establish the recovery time of the regulator and to provide stable operation. The potentiometer should be adjusted to provide fast voltage recovery during stable operation under normal load conditions.

Next, the feedback winding receives a voltage that is proportional to the output voltage; this provides stability during steady load conditions. A look at figure 11-13 will disclose that the load winding receives its power from transformer T1 and associated rectifiers. The current flow through these windings and load resistors R5 and R6 is regulated by the degree of magnetization of the reactor cores, which is established by the current flow in the various control windings.

In figure 11-13 also notice that when the input signal is not zero the currents through R5 and R6 are not equal. The unequal currents in these resistors provide a potential difference which is the output signal for this stage. The polarity of this signal depends upon the polarity of the error signal input.

The output stage (second stage of the regulator) is a 3-phase, full-wave, magnetic amplifier, as shown in figure 11-14. The output of the first stage, which we have just discussed, is fed into the control winding of the second stage. The output of this stage is the generator exciter-regulator field voltage. The magnitude of this voltage is established by the magnitude and polarity of the input signal, the bias current which is adjustable by P7, and also by the feedback current which is proportional to the output.

This type of regulator is desirable, since it functions on a very small change in voltage. Because of the operating characteristics of this type of regulator, it holds variations in the output voltage to within 1 percent.

In this discussion the various adjustments on the unit, with the exception of those on P1 (fig. 11-12), have been mentioned. Those adjustments are to be accomplished only on the bench when the regulator is being calibrated. Potentiometer P1 is located in the center of the front face of the regulator adjacent to the voltmeter jacks. The potentiometer may be adjusted while the regulator is installed on the aircraft to set the bus voltage to the value desired.

The voltage regulator is divided into three main parts. They are the voltage error detector, the preamplifier, and the power amplifier. These three units work together in a closed-loop circuit with the generator exciter regulator winding to maintain a nearly constant voltage at the generator output terminals.

The function of the error detector is to sample the generated voltage, compare it with a fixed standard, and send the error to the preamplifier. The detector consists of a 3-phase rectifier, a variable resistor for voltage adjustment, and a bridge consisting of two voltage reference tubes and two resistors. In operation, if the generator voltage ranges above or below its rated value, a current will flow either in one direction or the other, depending on the polarity developed in the bridge circuit.

The preamplifier receives an error signal from the voltage error detector. With the use of magnetic amplifiers it raises the signal to a sufficient level to drive the power amplifier to full output required for proper excitation.

The power amplifier delivers a signal to the exciter regulator winding; its magnitude depends on the signal from the preamplifier. This raises or lowers the voltage of the exciter regulator winding, which in turn raises or lowers the output voltage of the generator. For more information on magnetic amplifier regulators consult the applicable Service Instructions Manual.

The general operating principles just described apply to all static regulators currently in use. Various regulators differ, however, in some functions. For instance, one type employs two stages of magnetic amplication, where another has only one. The regulator discussed in this chapter is used on

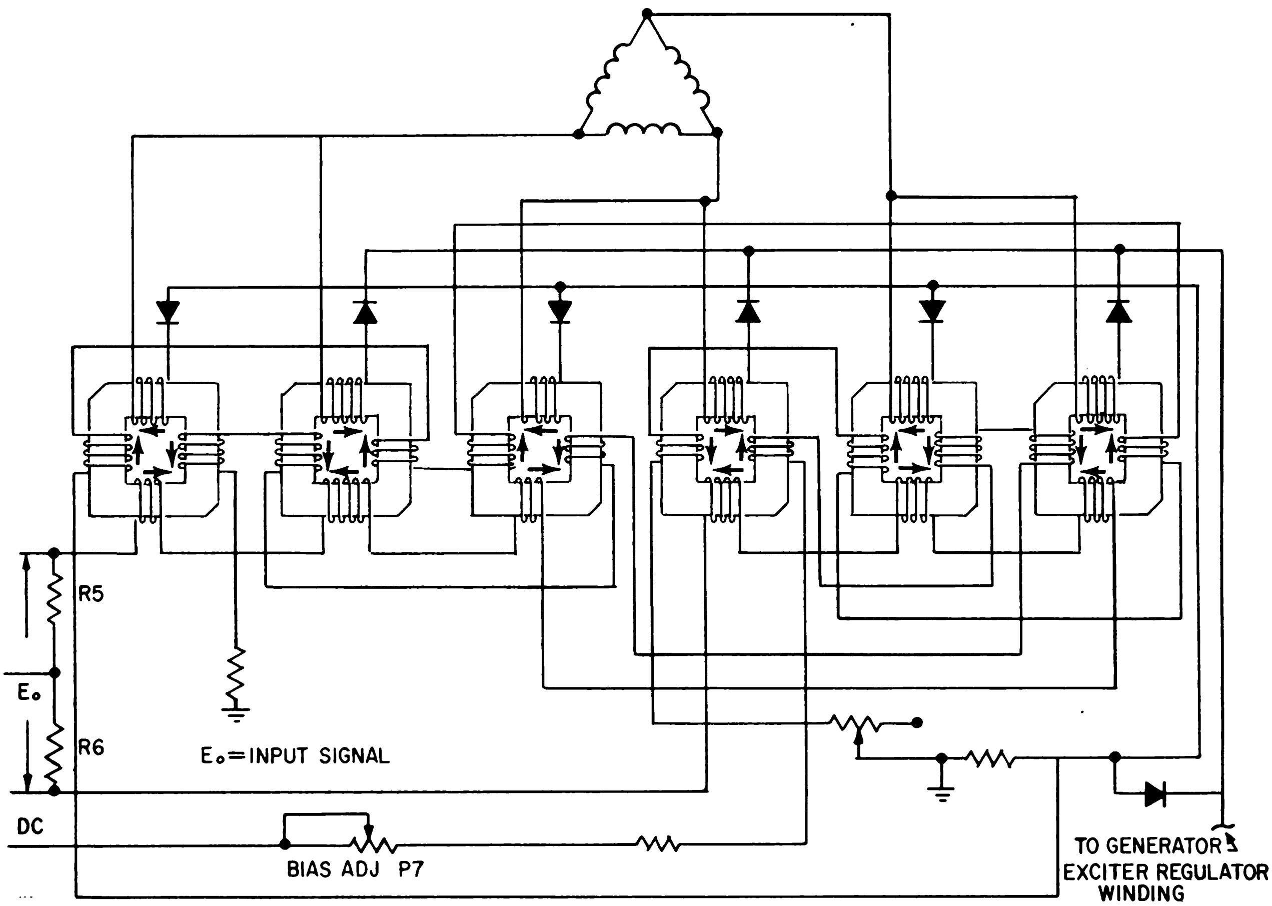


Figure 11-14.—Second magnetic amplifier stage.

a current operational naval aircraft. A careful study of its operation will be helpful in understanding similar regulators used in other applications.

The heart of the regulator is a voltage sensing bridge circuit (fig. 11-15). The complete regulator used for the explanation of a magnetic amplifier regulator is shown in figure 11-16.

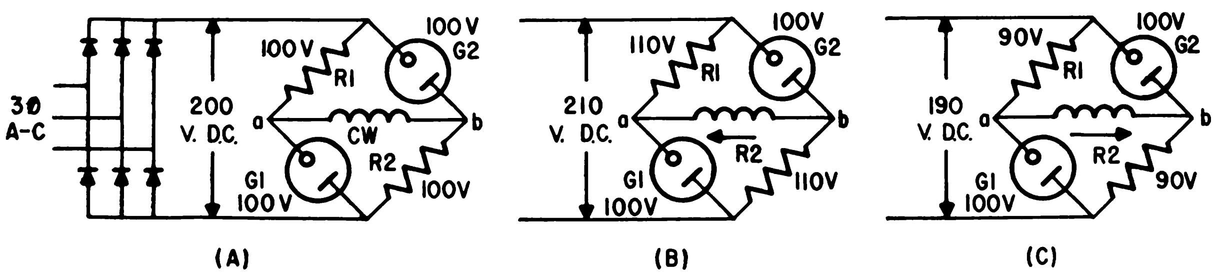


Figure 11-15.—Line voltage-sensing bridge.

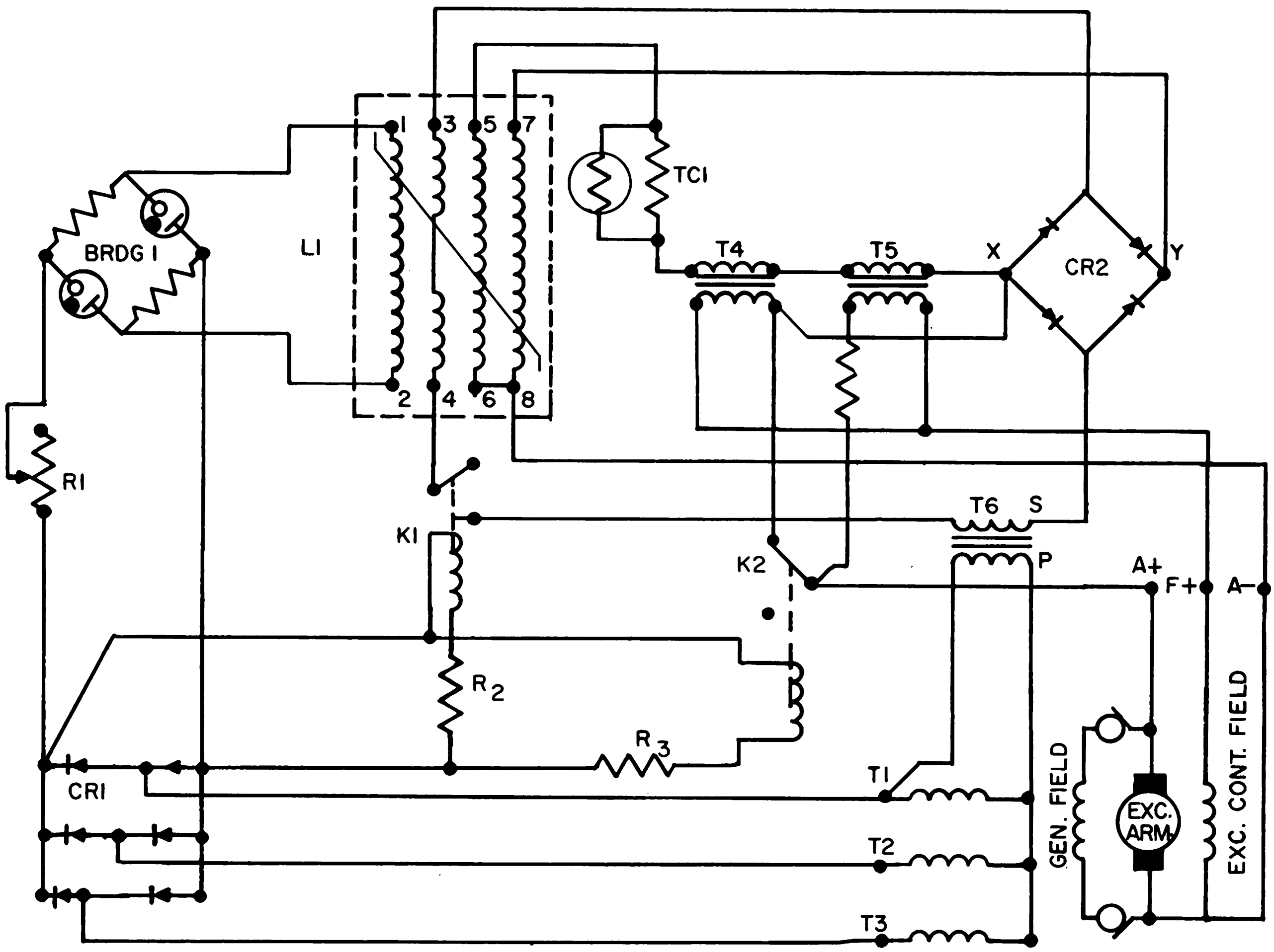


Figure 11-16.—Schematic of magnetic amplifier regulator.

BRIDGE CIRCUIT

Figure 11-15 (A) illustrates the primary features of the voltage-sensing bridge circuit. The line a-c voltage is rectified to a nominal value of 200 volts d.c. and applied across a bridge consisting of R1, G1, R2, and G2. Resistors R1 and R2 are fixed resistors. Tubes G1 and G2 are of the gas-discharge type, commonly referred to as voltage regulator (VR) tubes. Since they possess only a cathode and plate, they are rugged and are not subject to the common causes of failure in ordinary electron tubes. The most important feature of these tubes, however, is their ability to maintain a constant voltage drop across themselves regardless of changes in voltage applied to the bridge. The tubes used in figure 11-15 (A) maintain a constant drop of 100 volts. When line voltage is at the proper value, the d-c bridge voltage is 200 volts. The ohmic value of R1 and R2 is such that their voltage drops are the same as the voltage drops of the tubes. Under these conditions, the bridge is balanced and no current flows between points a and b through the control winding CW. In part (B), line voltage has risen to 210 volts. Since G1 and G2 cannot change their drops, the increase of applied voltage appears across R1 and R2. Thus, the increase of applied voltage alone has caused an unbalanced bridge, and current flows from b to a. In part (C), where line voltage dropped to 190 volts, tubes G1 and G2 still have a drop of 100 volts. The decrease of applied voltage appears across R1 and R2, and the bridge is unbalanced in the opposite direction.

From the foregoing, it can be seen that the essential function of the bridge circuit is to translate a variation of line a-c voltage into a current through the control coil.

Figure 11-16 is a complete regulator, showing how the bridge sensor is connected.

A complete sequence of operation is as follows:

At the start, generator voltage is zero and relays K1 and K2 are in the position shown. During the initial buildup of voltage, the residual d-c output of the exciter armature is connected directly to the exciter control field through terminal A+ and K2, through the lower winding of stabilizer transformer T4, and then through F+ to the field. This causes a rapid buildup of exciter voltage, and consequently a rapid buildup of a-c output voltage through T1, T2, and T3. When line voltage has risen to a near-normal level, the output of CR1 is sufficient to actuate relays K1 and K2. With armature of K2 pulled down, exciter output no longer goes directly to the control field, but instead goes only through T5 to F+ and through the exciter control field to A-, and is used thereafter only as a stabilizer reference during normal operation. When the armature of K1 is pulled down, the output of T6's secondary is routed through the load windings 3-4 of the saturable reactor L1 to rectifier CR2. T6 thus takes over the function of supplying power to the exciter control field. The output of T6 is rectified by CR2, and the d-c is routed from terminal X on CR2 through T4 and thence to F+ and the field.

The amount of power that T6 may ultimately pass to F+ is governed by the impedance of the series load windings 3-4 in L1. These windings' impedance in turn is regulated by the bridge-powered d-c control winding 1-2. The complete regulating loop can now be seen. A-c line voltage at T1, T2, and T3 acts through CR1 and BR1 into L1. This governs the output of T6 through L1, CR2, and T4 into the exciter control field. In turn, the exciter control field regulates the exciter armature voltage, and thus generator field strength, and finally the output a-c voltage at T1, T2, and T3.

From terminal X on CR2, d.c. is also routed through T4, T5, and the temperature-compensator TC1. This d.c. goes further for it flows downward through L1's winding 5-6, upward through winding 8-7, and finally back to its rectifier source at terminal Y. This circuit is used for biasing the saturable reactor L1 at the proper operating level.

Winding 8-7 serves an additional purpose. This is explained as follows. To make a complete circuit, exciter control field current must flow from X on CR2 through the lower winding of T4, through the field, and then back upward through A-, winding 8-7, and finally into terminal Y on CR2. Since the bias winding 8-7 is thus seen to be in series with the control field, then it follows that any variation in the control field current will also cause a variation in the biased output level of L1. An increase in control field current causes a decrease in L1's output, because of the way in which 8-7 is wound. Winding 8-7, therefore, is employed as a stabilizing negative-feedback winding, as well as for bias balancing. The same stabilizing effects are accomplished by transformers T4 and T5.

Voltage adjustment is made with R1. When R1 is positioned to increase the voltage applied across BRDG1, the bridge will immediately act to decrease line a-c voltage and the output of CR1 until bridge voltage is depressed to its original value.

TESTING, ADJUSTING, AND CHECKING

Aircraft Electrical Power Equipment, NW 17-15BA-500, contains directions for connecting magnetic amplifier regulators to test stands for testing and adjusting. Refer to this or other pertinent publications before attempting to adjust a regulator.

After the regulator has been connected to the test stand, the following resistance settings must be made. (See fig. 11-11.)

1. Set the gain resistor to maximum resistance.
2. Set the stability resistor to one-half of maximum resistance.
3. Set the frequency compensation resistor to the center of its range.

With the generator running at 4,800 rpm, close the exciter field switch on the test stand. The voltage range from line to neutral should be 115 volts ±10 volts. Set the voltage to approximately 120 volts from line to neutral and place full load at rated power factor on the generator at 6,000 rpm. Maintain this condition for a period of 5 to 10 minutes to allow the generator and regulator to warm up. After the regulator has warmed up, set the

voltage adjustment potentiometer (fig. 11-11) to the minimum voltage position and measure the voltage from phase to ground; the voltage should be approximately 111 volts. Now set the voltage potentiometer to maximum volts and measure the voltage output from phase to ground; the voltage should be approximately 120 volts. Set the voltage potentiometer to 115 volts ±0.5 volts phase to ground on all phases and lock the voltage adjustment potentiometer. At generator speeds of 4,800, 6,000 and 7,200 rpm, place on and remove several times a balanced 3-phase load of 15 kw. The voltage must remain within the range of 112.5 to 117.5 volts for all conditions of generator load and speed. If while performing the test the voltage regulator allows the voltage to (1) hunt or (2) to rise to 140 volts without control, the regulator should be returned to overhaul.

No cleaning of the magnetic amplifier regulator is required other than to remove any accumulation of dirt and dust. In most cases this may be removed by blowing with moisture-free compressed air.

Check for loose or broken connections, worn or damaged insulation, faulty wiring, and burned or discolored wiring or parts. Make sure that all mounting hardware is secure. Check for signs of corrosion and for leakage of capacitors. Check for large black spots on the rectifiers; these spots may indicate defective units. With an ohmmeter, check all wiring for continuity. Rectifiers should be checked by disconnecting all the leads to one terminal and measuring rectifier resistance with an ohmmeter in both the forward and reverse directions. The resistance should be considerably higher in the reverse direction. If the resistance measures low in both directions, the rectifier is defective. Capacitors may be checked for short circuits by disconnecting all of the leads to one terminal and measuring capacitor resistance; the resistance should be one megohm or more. When reconnecting the leads to the parts, care should be taken to maintain the flexibility of the leads and to prevent wiring from rubbing on sharp edges of parts or hardware.

Table 11-1 is a troubleshooting chart for the magnetic amplifier regulator. Refer to figure 11-16 when studying this chart.

TRANSISTORIZED VOLTAGE REGULATOR

A voltage regulator which has no mechanical moving parts (except the exciter control relay) is the transistorized regulator.

Before going into this system, review chapter 2 of Basic Electronics, NavPers 10087-A.

The a-c output of the generator is fed to the voltage regulator where it is compared to a reference voltage, and the difference is applied to the control amplifier section of the regulator. (See fig. 11-17.) If the output is too low, field strength of the a-c exciter generator is increased by the circuitry in the regulator. If the output is too high, the field strength is reduced.

The power supply for the bridge circuit is CR1, which provides full-wave rectification of the 3-phase output from transformer T1. The d-c output voltages of CR1 are proportional to the average phase voltages. Power is supplied from the negative end of CR1 through point B, R2, point C, Zener diode (CR5), point D, and to the parallel hookup of V1 and R1. Takeoff point C of the bridge is located between resistor R2 and the Zener diode. In the other leg of the reference bridge, resistors R9 and R7 and the temperature compensating resistor RT1 are connected in series with V1 and R1 through points B, A, and D. The output of this leg of the bridge is at point E.

As voltage changes occur, for example if the generator voltage lowers, the voltage across R1 and V1 (once V1 starts conducting) will remain constant, leaving the total voltage change occurring across the bridge. Since the voltage across the Zener diode remains constant (once it starts conducting) the total voltage change occurring in that leg of the bridge is across resistor R2. In the other leg of the bridge, the voltage change across the resistors will be proportional to their resistance values.

Therefore, the voltage change across R2 is greater than the voltage change at point E. If the generator output voltage were to drop, point C would be negative with respect to point E. Conversely, if the generator voltage output were to increase, the polarity of the voltage between the two points would be reversed.

The bridge output, taken between points C and E, is connected between the emitter and the base of transistor Q1. With the generator output voltage low, the voltage from the bridge is negative to the emitter and positive to the base. This is a forward bias signal to the

Table 11-1.—Troubleshooting chart for magnetic amplifier regulator.

Trouble	Probable cause	Remedy
Relay does not pickup.	Open resistor (R3). Open relay coil. Incorrect connections on test panel or generator. Regulator wiring internally open.	Replace resistor. Replace relay. Check and correct wiring. Check and correct wiring.
Relay does not pickup and potentiometer has no control.	Both VR tubes shorted. Open gain resistor. Open or shorted wiring on reactor.	Replace tubes. Replace resistor. Return to overhaul.
Relay does not pickup, potentiometer has control but voltage too high even at lowest setting.	Faulty rectifier. Open reactor. Open transformer (T4 or T5).	Replace rectifier. Return to overhaul. Return to overhaul.
Regulates properly at low speed but goes to ceiling voltage at high speeds.	Open or reverse connection on generator field.	Rewire or repair.
Relay chatters.	Shorted VR tubes. Open wirings in reactor. Partially open transformer (T6).	Replace tubes. Return to overhaul. Return to overhaul.
Voltage steady but lower than normal, adjustment of potentiometer has little effect.	Shorted VR tubes. Faulty rectifier (CR2).	Replace tubes. Replace rectifier.
Smoking and discoloration of components.	Short circuit within the regulator. Faulty regulator components.	Check wiring and correct. Return to overhaul.

transistor and the emitter to collector current therefore increases. With the increase of current, the voltage across emitter resistor R11 increases. This, in turn, applies a positive signal to the base of transistor Q4, increasing its emitter to collector current and increasing the voltage drop across the emitter resistor R10.

This gives a positive bias on the base of Q2, which increases its emitter to collector current and increases the voltage drop across its emitter resistor R4. This positive signal controls output transistor Q3. The positive signal on the base of Q3 increases the emitter to collector current.

The control field of the exciter generator is in the collector circuit. Increasing the output of the exciter generator increases the field strength of the a-c generator, and this increases the generator output.

To prevent exciting the generator when the frequency is at a low value, there is an underspeed switch located near the F+ terminal. When the generator reaches a suitable operating frequency, the switch closes and allows the generator to be excited.

Resistors R27, R28, and R29 are connected in series with the normally closed contacts of the relay K1. Relay K1 is connected across the power supply (CR4) for the transistor amplifier. When the generator is started, electrical energy is supplied from the 28-volt d-c bus to the exciter generator field to "flash the field" for initial excitation. When the field of the exciter generator has been energized, the a-c generator starts to produce and, as its

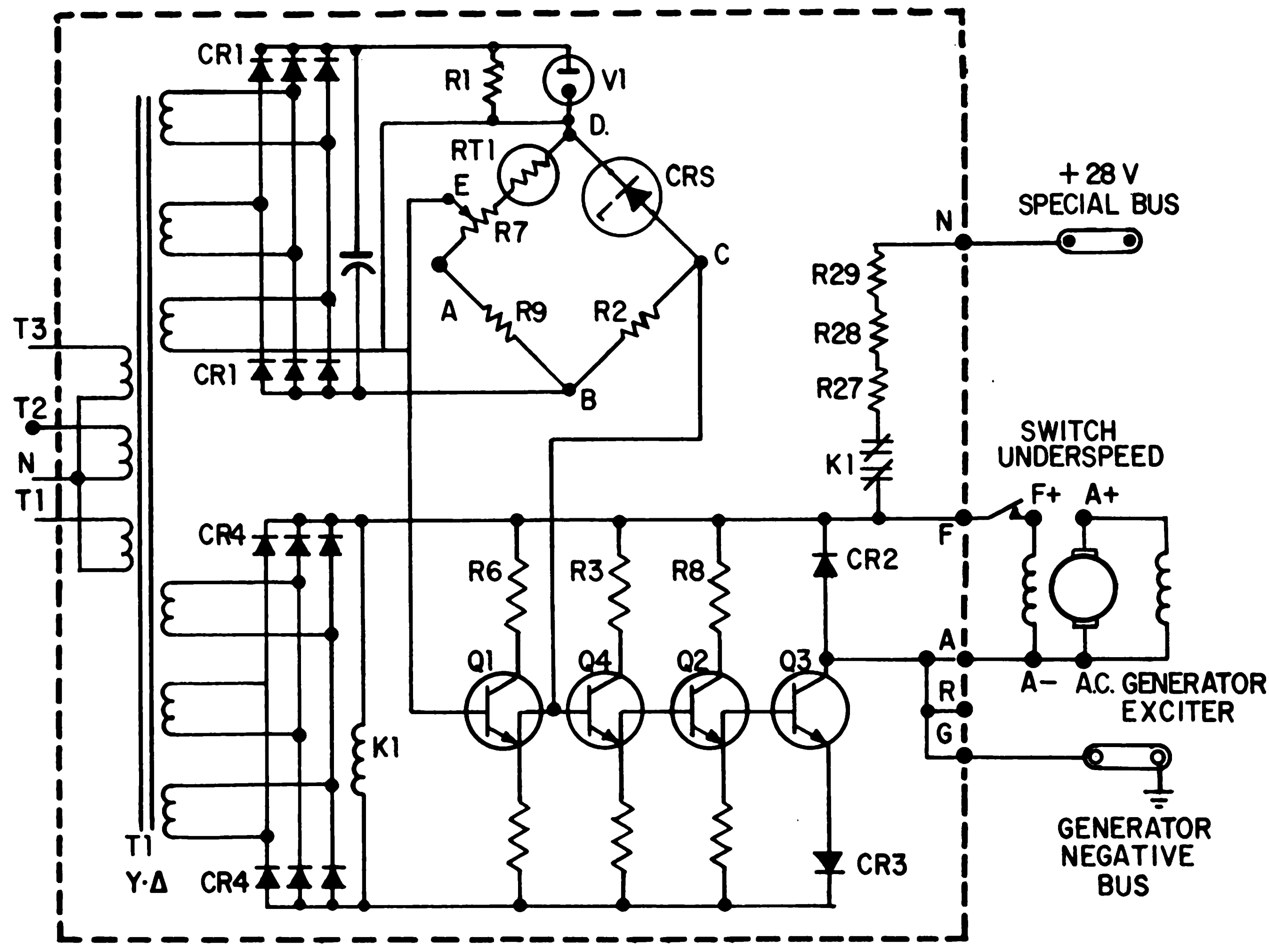


Figure 11-17.—Transistorized voltage regulator.

output voltage increases, relay K1 is energized, opening the "field flash" circuit.

Another type of transistorized voltage regulator (fig. 11-18) operates by sensing the voltage existing on the lines, amplifying the changes in this signal, and varying the average current supplied to the field winding of the integral exciter. The voltage regulator consists of a sensing circuit with input rectifiers, a temperature compensated Zener diode reference and error detecting bridge, and a three-stage transistor amplifier. The output of the bridge circuit is a voltage inversely proportional to the difference between the generator voltage and the regulator set voltage and is referred to as the error signal.

The output of the 3-phase a-c generator is supplied through transformer T1 in the regulator to provide isolation from the generator and to deliver correct utilization voltages. The output of the transformer is then passed through the full-wave bridge rectifier (CR1) to obtain a direct voltage to supply the comparison circuit. The output of the rectifier is proportional to the average of the three line voltages and is applied to the voltage reference and error detecting bridge. This voltage is then compared to the constant voltage present across the Zener diode (CR5), and a means of telling whether the generator is too high or too low is achieved. Potentiometer R7 permits adjustment to the desired voltage. The glow tube (V1) serves to increase the sensitivity of the voltage reference and error detecting bridge. Thermistor RT1 provides temperature compensation in the comparison circuit to offset

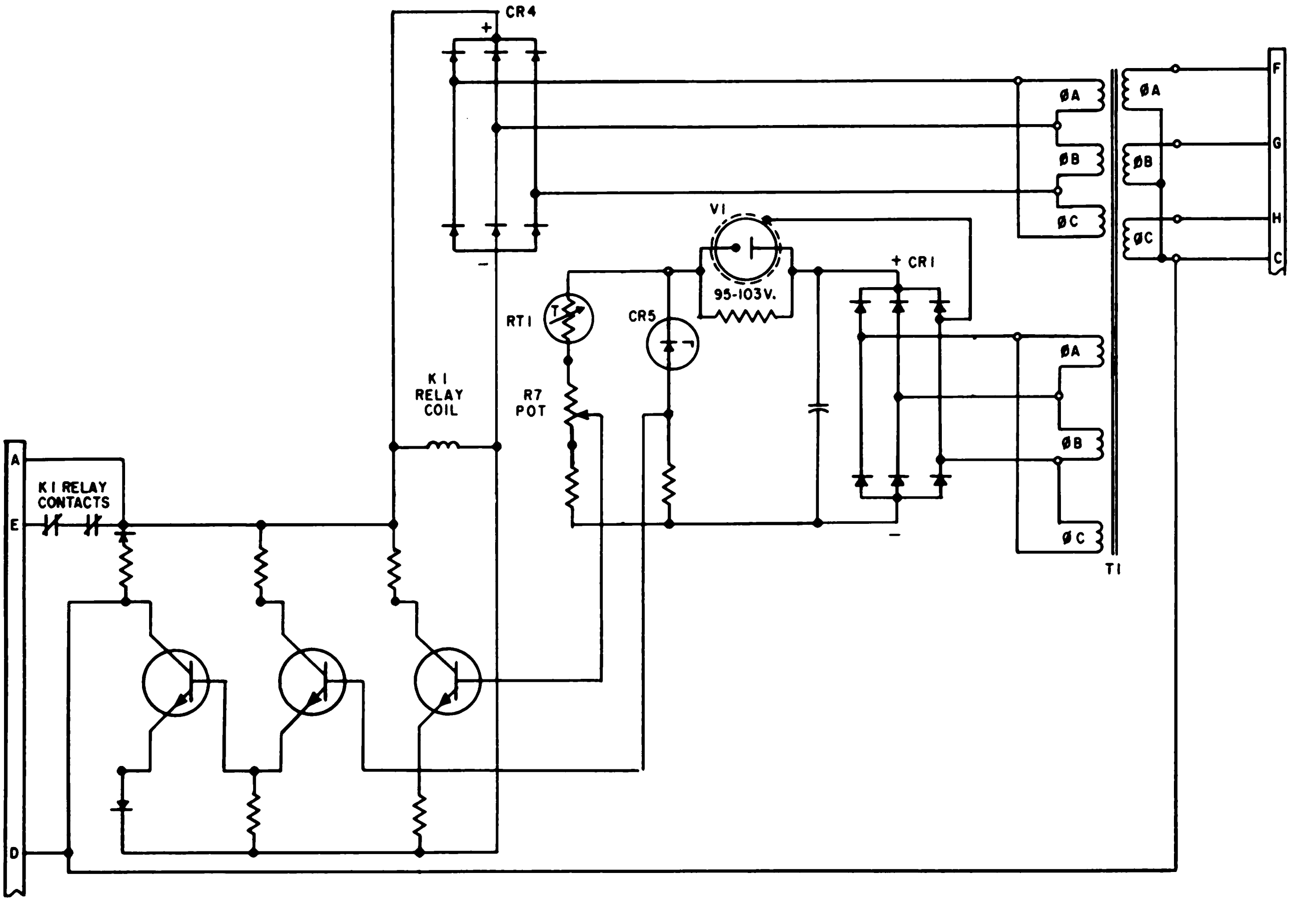


Figure 11-18.—Transistorized voltage regulator schematic.

the effects of changes in the other elements of the circuit resulting from temperature variations so that a nearly constant voltage is held.

The output voltage of the error detecting bridge has a sawtooth wave shape due to the ripple resulting from the semifiltered 3-phase rectifier supply. This sawtooth voltage is applied to the input of the first stage of the three-stage transistor amplifier, and with the second and third stages being overdriven, an essentially square wave output is obtained. The effect of the error detecting bridge output is to modulate the width of the pulses that are being passed through the amplifier so that the output current to the shunt field of the integral exciter is varied by varying the width of the square wave impulses.

The power for operating the three-stage transistor amplifier is supplied through the full-wave bridge rectifier (CR4) from transformer T1. Obtaining the amplifier power supply in this manner requires special consideration since there are times when excitation is required and no voltage is available to supply the amplifier. Such conditions exist during initial buildup of system voltage from rest, and during 3-phase short circuit on the generator. A control relay (K1) connected across the full-wave bridge rectifier (CR4) overcomes these obstacles since, with the relay deenergized, the exciter is self-excited. When the generator voltage is approximately 90 volts line to line, the voltage across CR4 is sufficient for the control relay (K1) to pick up, removing the self-excited field circuit, and the exciter shunt field is then supplied from the voltage regulator as a separately excited machine. No feedback network or stabilizing transformers are necessary in this voltage regulator due to the absence of phase shift and the fast response characteristics of the transistor type amplifier.

CHAPTER 12

A-C POWER SYSTEMS

Most current aircraft that have large a-c power loads utilize two or more 3-phase a-c generators. When the a-c system has no provision for connecting the a-c generators in parallel, a dual bus system is installed. Each bus is supplied power by its respective a-c generator; however, should one a-c generator fail, its loads are either manually or automatically transferred to an operating a-c generator. This is usually accomplished by connecting the buses together with a relay. Present-day a-c generators are of such capacity that one a-c generator is usually capable of providing power for the full load; there may be exceptions to this in some installations, and in such cases when one a-c generator fails, some of the load should be removed from the circuit.

GROUNDED AND UNGROUNDED SYSTEMS

GROUNDED SYSTEMS

The term grounded system means that one leg of the system is connected to a common conductor, such as the earth, the skin of the aircraft, or to a structural member of the aircraft. When the grounded leg of the circuit is connected to a good electrical conductor, this conductor may serve as one leg of the circuit; thus, no separate conductor is needed for this leg of the circuit.

Figure 12-1 shows a simple grounded system. Even though the grounds are shown at different points, the potentials at these points are essentially the same since they are connected to a common conductor.

Any wire that completes the circuit to the grount network for an equipment is designated with the letter N. Any wire so designated may come in contact with ground at any point without causing malfunction of the equipment.

Grounding is accomplished in 3-wire systems by grounding one of the phases, usually the B-phase in aircraft. In 4-wire systems the neutral is grounded. Care must be taken to insure that the same phase is grounded in all equipments. Figure 12-2 shows the grounding of 3-wire systems.

The grounded type circuit is advantageous since it reduces overall weight by using fewer conductors. This results in a reduction in cost and space requirements. Other advantages are that troubleshooting is simplified to some extent and the impedance of the ground return path is lower than that of a run conductor. The disadvantages of a grounded system are as follows: First, short circuits will result when a bare spot on any ungrounded conductor of the system touches ground; and second, where circuits of different potentials and frequencies are using a common ground, there is the possibility of one circuit feeding into another. This trouble is more pronounced in electronic circuits.

UNGROUNDED SYSTEMS

The term ungrounded system means that the circuit is in no way connected to ground; thus, all conductors are run from the power source to the loads. Circuits of this type are often referred to as being above ground. The ungrounded system has the following advantages: It prevents one circuit from feeding into another; no malfunction of equipment will occur should one conductor become accidentally grounded; and the circuits are completely insulated from each other. The system has the disadvantage of adding more weight because it requires more conductors than the grounded system. This results in added cost and space requirements.

Both the grounded and ungrounded systems have their specific usage in modern aircraft. The grounded system utilizes the skin of the aircraft for one side of the line. The ungrounded

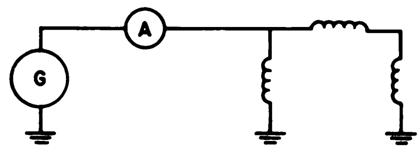


Figure 12-1.—Grounded system.

system is completely isolated. The type of system to be used depends upon the factors required of the circuit.

SINGLE-PHASE AND POLYPHASE SYSTEMS

A single-phase distribution system of electrical energy employs single-phase current. This current may be obtained from a single set of generator coils or transformer windings. The system may be either 2-wire or 3-wire. The 2-wire system may be either a grounded system utilizing the skin of the aircraft as the return, or an ungrounded system. Normally, the 3-wire system is not used in aircraft. The single-phase distribution system is similar in construction to a d-c distribution system.

A polyphase distribution system is one in which two or more alternating voltages of the same frequency are applied to the same circuit or network. These voltages are displaced in phase by a fixed amount in relation to each other.

The two most used types of polyphase systems are the 2-phase and the 3-phase. The 2-phase system is usually a 4-wire system that uses 2 wires per phase. The voltages of each phase differ from each other by 90 degrees. This type system actually constitutes 2 single-phase systems. Autopilot and compass circuits utilize this type system.

Three-phase systems are the most commonly used of all polyphase systems and are utilized to a large extent in modern aircraft. In this system the voltage of each phase differs from each other by 120 degrees.

The network may be either a 3-wire grounded or ungrounded delta or wye system, or a 4-wire grounded or ungrounded wye system. The 4-wire wye system tends to keep the system balanced.

COMPARISON OF SINGLE-PHASE AND POLYPHASE SYSTEMS

Single-phase systems are of simple design and construction and are utilized where relatively low power is required. Polyphase systems are more complicated in construction and design are used where high power is required; they provide a "smoother" source of power.

Single-phase power may be obtained from polyphase systems. When this is done, care must be taken to keep the load on the polyphase system balanced. Balancing loads are discussed later in this chapter.

POWER FACTOR

POWER IN A-C CIRCUITS

In a d-c circuit, power is computed by the equation, P = EI; that is, watts equals volts times amperes. Thus, if 1 ampere flows in a circuit at a pressure of 200 volts, the power is 200 watts. The product of the volts and the amperes is the TRUE POWER in the circuit.

In an a-c circuit, a voltmeter indicates the effective voltage and an ammeter indicates the effective current. The product of these two readings is called the APPARENT POWER. Only when the a-c circuit is made up of pure resistance is the apparent power equal to the true power. When the impedance of the circuit is either inductive or capacitive, the current and voltage are not exactly in phase, and the true power is less than the apparent power. The true power may be obtained by a wattmeter reading. The ratio of the true power to the apparent power is called the POWER FACTOR, and is equal to true power divided by apparent power.

It is desirable that equipment utilizing a-c power have as near a unity power-factor load as practicable. This improves the efficiency of power distribution by reducing the line current and I^2R losses. Most a-c loads in an aircraft are somewhat inductive, resulting in a lagging power

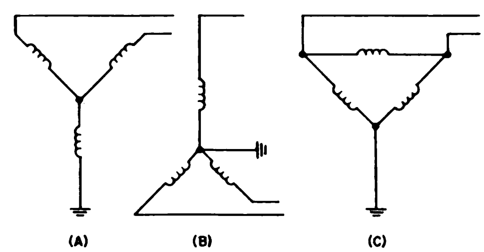


Figure 12-2.—Grounded 3-wire systems. (A) Grounded 3-wire wye; (B) grounded 4-wire wye; (C) grounded delta.

factor. Power-factor correction may be accomplished by connecting a capacitor of the proper capacitance in parallel with the circuit. The connection should be made as close to the inductive load as possible.

The nonenergy component of the current in the inductive branch is 180° out of phase with the capacitive current. These currents circulate between the capacitor and inductive load and do not enter the line. The vector sum of capacitor current and total inductive load current is equal to line current. The line current is now in phase with the applied voltage to the parallel combination of the inductive load and the capacitor. This reduction in line current reduces line loss and increases the efficiency of transmission.

An application of power-factor correction has been given in chapter 7 in connection with the single-phase a-c generator. Additional information on power factor and power-factor correction may be found in Basic Electricity, NavPers 10086-A, on the subject "Power and Power Factor."

WYE, DELTA, AND OPEN-DELTA SYSTEMS

Most 3-phase distribution systems utilize either the wye or delta connection. The voltage and current relationships of these systems are covered in chapter 7 under the heading "Three-Phase A-C Generator."

OPEN-DELTA SYSTEM

An advantage of a delta connection system is that if one winding of the power source becomes inoperative, it may be disconnected and the system can still operate at 57.7 percent of capacity. But in a wye connection, if one winding of a 3-phase system is damaged or disconnected, it is not possible to operate the system. When power is distributed in this manner, it is known as an open-delta system. For a detailed description of open-delta operation, refer to Basic Electricity, NavPers 10086-A, under the heading "Three-Phase Connections."

The principal reasons for using a wye-connected distribution system are that two different voltages are obtainable from the same source; an economy in transmission results because the line voltage is 1.73 times greater than the phase voltage, and the line current is equal to phase current. Thus, the line losses are reduced, and the efficiency of transmission is improved.

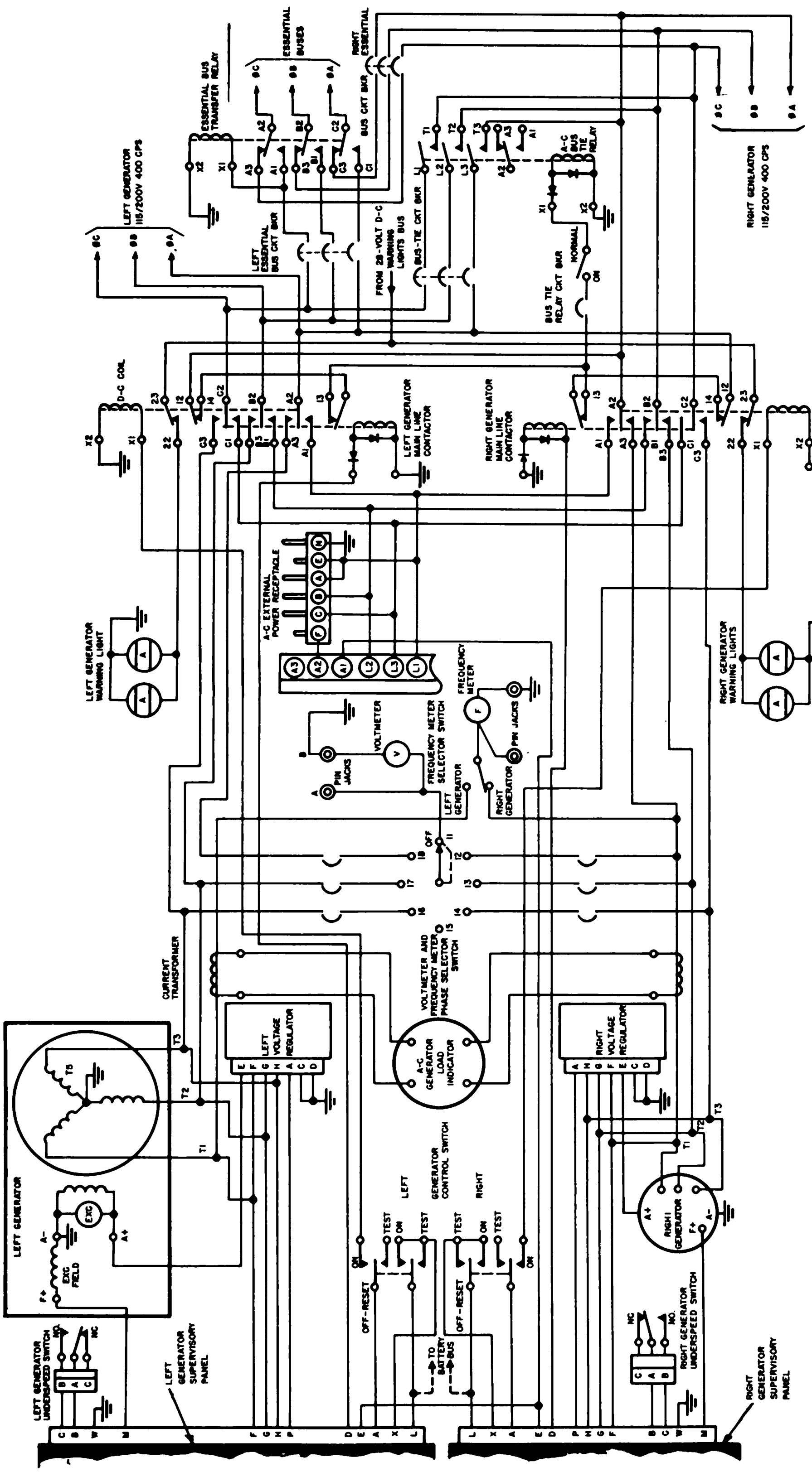
VARIABLE FREQUENCY POWER SOURCES

Since the a-c power requirements of aircraft vary, depending on type and use, a-c power supply equipment also varies. Most a-c systems provide one or more sources of 120/208 volts 3-phase and 120 volts single-phase. When the system is connected for 3-phase operation, either 208 or 120 volts are available at the bus. By proper connection to the 3-phase bus, 120 volts single-phase power may be obtained. The frequency of the a-c supply is either 400 cps (fixed frequency) or it is a variable frequency that varies from 400 to 800 cps. The factors which determine whether the output current will be a fixed or a variable frequency are the method of drive or the design of the a-c generator.

The sources of a-c power are either engine-driven generators or inverters which are electrically driven from the d-c system. In many aircraft where the a-c power requirement is large, a combination of generators and inverters is used. In late-model aircraft the a-c generator system supplies most of the electrical power required to operate the electrical, electronic, and instrument systems. Most late-model aircraft such as the E-2A and A-6A are not equipped with d-c generators. Whenever a source of d-c power is necessary, it is obtained from a system of diodes, which are fed from the a-c system. A typical rectifier unit consists of a transformer and wye or delta connected diodes (120/208 volts a.c. to 28 volts d.c.).

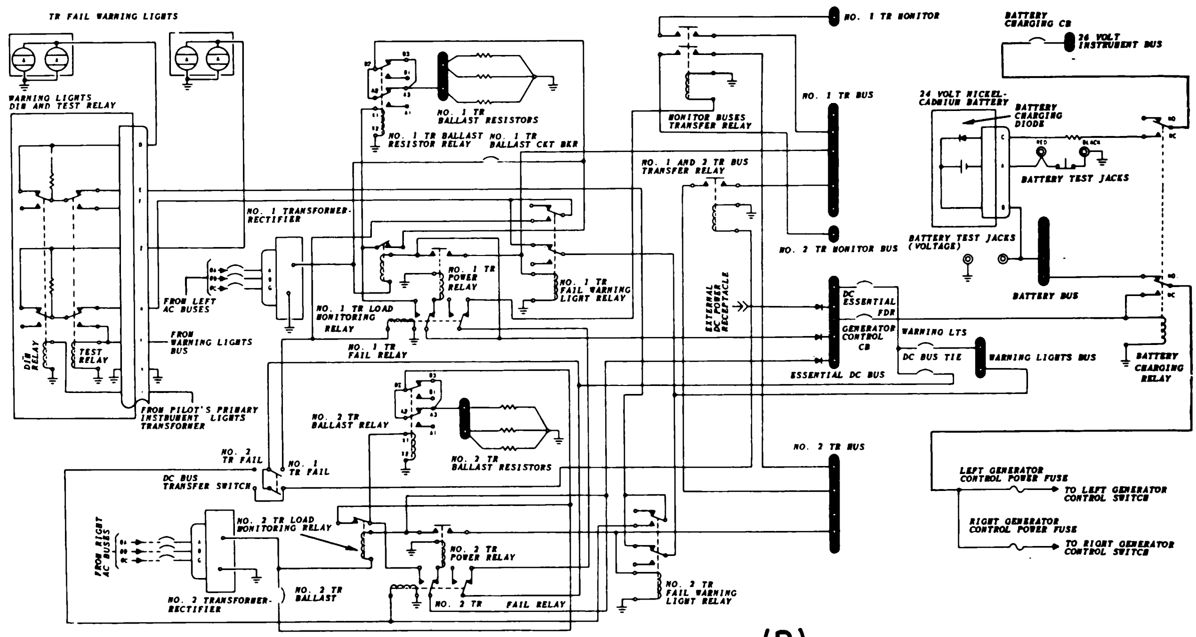
Some earlier aircraft use multiplate rectifiers instead of diodes to obtain a d-c course. This system uses a stepdown transformer and a multiplate rectifier. The number of plates in the rectifier determines the power output capacity.

Figure 12-3 (A) and (B) shows a typical a-c/d-c system used in a modern multiengine aircraft. By studying this figure, you will become familiar with the units that make up a complete system. The a-c generators (fig. 12-3 (A)) are driven by a constant-speed drive unit. The drive unit contains a governor assembly which enables the a-c generators to maintain a constant output frequency of approximately 400 cps over the complete range of prime mover (engine or turbine) operating speeds. Each generator is wye-connected and provides 3-phase power. Voltage regulators control the generator voltage by varying the current flow to the rotating d-c exciter field. The generator underspeed switch



(A)

Figure 12-3 (A).—Typical a-c/d-c system (a-c section).



(B)

Figure 12-3 (B).—Typical a-c/d-c system (d-c section).

prevents generator excitation until the constant-speed drive comes up to minimum operating speed.

Sensing circuits in the supervisory panels protect the electrical system from damage when a malfunction occurs in a generator or system. These sensing circuits respond to overvoltage, continuous undervoltage, and underfrequency conditions. The sensing circuits function to de-energize and disconnect the generator from the line.

Generator warning lights and a-c load indicators provide visual indications of system performance. Illumination of a generator warning light indicates that the generator has been disconnected from its load buses.

Each generator is controlled by a single generator control switch of the double-pole, double-throw type. When a control switch is in the ON position, the generator builds up voltage and is connected to the system. With the switch in TEST, the generator becomes energized so that its output may be checked, the main contactor is open, and no connection is made to the buses. When the switch is OFF, the exciter field is open and the generator is shut down. In figure 12-3 (B), the d-c power supply system is shown. Two transformer-rectifiers convert the generator output to supply the d-c power requirements of the aircraft. Each transformer-rectifier supplies 28 volts d.c. When one transformer-rectifier fails, the load is manually switched to the operating transformer-rectifier by the d-c bus transfer switch. The rectifiers are automatically connected to ballast resistors to maintain proper voltage output during periods when the d-c load is less than 10 amperes.

A battery serves as an emergency d-c power supply and is connected directly to the battery bus.

BALANCING LOADS

Unbalanced loading will cause unequal phase voltages and possible overloading of one of the phases. Since there is only one field winding in the a-c generator, the voltage regulator cannot maintain the desired voltages of each phase independently; thus, if one phase is overloaded, the other phase voltages may be too high.

It is always important that the various single-phase loads connected to the 3-phase system be distributed so as to present a balanced load. For example, if four separate single-phase loads

are connected to a 3-phase system, the two smaller loads should be connected to the same phase, one of the larger loads connected to one of the remaining phases, and the other load to the third phase.

TRANSFORMERS

POWER TRANSFORMERS

Power transformers find many uses in naval aircraft equipment such as automatic pilots and remote indicating compasses. These are single-phase, constant-potential transformers with one or more secondary windings, or a single secondary with several tap connections. Aircraft power supply transformers are designed for a frequency range from 380 to 420 cps. (NOTE: The basic principles of transformer operation are given in Basic Electricity, NavPers 10086-A, under the heading "Transformers.")

AUTOTRANSFORMERS

The autotransformer is similar in most respects to an ordinary transformer except that it has only one winding, part of which is common to both parts of the circuit. Within the limits of its application, it offers a saving in both size and cost over conventional units. These savings are greatest when the turns ratio is less than 2 to 1 (either step-up or step-down), and diminish to insignificance when the turns ratio increases beyond about 8 or 10. A feature which is sometimes objectional is that there is no isolation between primary and secondary positions of the circuit. For this reason it would not be employed to step down a very high voltage, as there is danger that the secondary may be subjected to the primary voltage.

Referring to figure 12-4, the saving in wire is a result of the fact that the section of the winding between B and C is common to both primary and secondary circuits, and carries the algebraic sum of both currents. But since the primary and secondary currents are of opposite sign (that is, they are out of phase), this actually means that it carries the difference between these currents, often permitting a reduction in the size of the conductor for this portion of the winding. An additional saving results in the omission of a separate secondary winding.

The turns ratio and other details of the circuit are determined in the same manner as for conventional transformers.

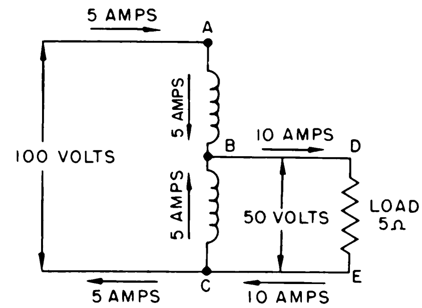


Figure 12-4.—Autotransformer.

The circuit in figure 12-4 shows an autotransformer with a turns ratio of 2-to-1 step-down, the tap at point B dividing the winding into two equal parts. With a load of 5 ohms connected as shown, the secondary current is computed by the formula $I = E/R$ or $50/5 = 10$ amperes. The power in the load therefore equals EI (50×10) or 500 watts. As in a regular transformer, this power comes from the primary by means of the magnetic field and, disregarding losses, the primary must take 500 watts from the line. The primary current would therefore be P/E (500/100) or 5 amperes. Only the difference between these two currents, which is 5 amperes, flows in the common portion C to B, as indicated by the arrow. Thus, when the turns ratio is 2:1 (either step-up or stepdown), the current in both sections of the winding is the same, and the cost and weight of an entire winding are saved.

The autotransformer in figure 12-5 has a turns ratio of 120/90 connected to a load which draws 20 amperes. This represents a secondary power of EI = (90×20) or 1,800 watts. The primary currents, neglecting losses, equals P/E (1,800/120) or 15 amperes. As in the previous problem, the current in the portion of the winding in BC which is common to both circuits is the difference between the primary and secondary line currents, or 5 amperes. The saving here is obvious. A conventional transformer of the same characteristics would require a 120-volt 15-ampere primary and a separate 90-volt 20-ampere secondary. Here all that is required is a 30-volt 15-ampere winding in series with a 90-volt 5-ampere winding, provided, of course, that the application at hand permits the use of an autotransformer. Thus, a 0.45kva autotransformer will supply this 1.8 kva load.

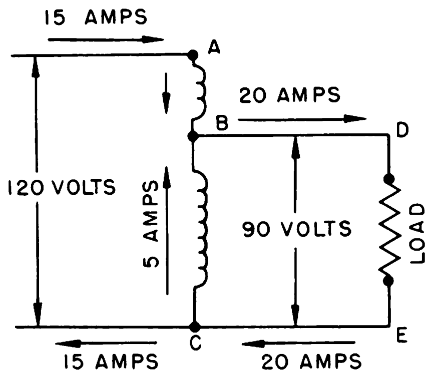


Figure 12-5.—Autotransformer.

There are many interesting uses of autotransformers. An autotransformer with a continuous variable tap is marketed under the name VARIAC, and is used for many purposes where a continuous control from zero to full (or even above) line voltage is required. The core in this case is made in the form of a ring (toroid), and the winding is usually in the form of a single layer covering almost the entire surface. A control shaft carries an arm and a brush which makes contact with each turn of the winding as the shaft is rotated. Thus, the setting of the shaft determines the turns ratio. One end of the winding goes to both line and load, and the other end goes to the line. The brush is connected to the other side of the load. If it is desired to obtain voltages in excess of line voltage, such as to compensate for abnormally low line voltage, the primary is connected to a tap at approximately 10 percent down from the end of the winding. This provides secondary control from zero to full line voltage, even though the actual line voltage is as much as 10 percent below normal.

A typical example of the application of an autotransformer in an aircraft power system is shown in figure 12-6. In this circuit an autotransformer steps down the 115-volt, 400-cycle primary power to 26 volts for instrument power.

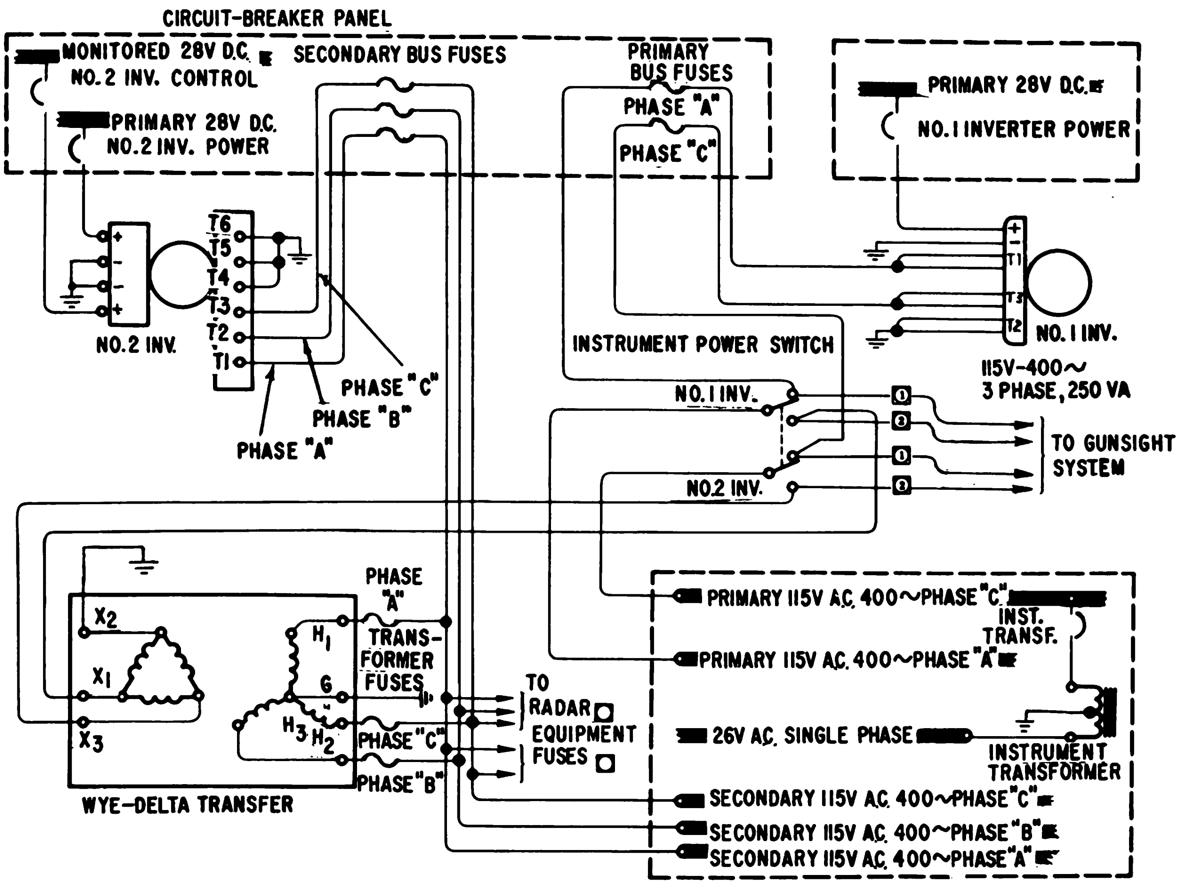


Figure 12-6.—A-c power supply system.

INSTRUMENT TRANSFORMERS

It is usually not practicable to connect meters directly to high-voltage and high-current a-c circuits. Therefore, meters are coupled to these circuits by means of instrument transformers. These transformers are divided into two general types—the current and the potential. These devices permit the use of standard low-voltage meters for all high-voltage or high-current a-c circuits, and at the same time protect the operating personnel from the high-voltage circuits. Instrument transformers are covered in detail in Basic Electricity, NavPers 10086-A.

TROUBLESHOOTING TRANSFORMERS

Simple checks can be made on transformers. The most common check is for an open transformer winding. Since a winding is a continuous length of wire, it should have a definite amount of resistance. If it shows resistance that is much greater than the normal value for that transformer when measured with an ohmmeter (on the high scale), the winding must be open. Open windings are usually the result of excessive current. This causes the wire to melt and separate at a certain point or to oxidize so much that it becomes thin and breaks.

A number of different types of shorts can develop in a transformer. The different windings can become shorted together. This trouble can be located by checking the resistance between the windings. The resistance between any two windings should be infinite. A winding can also become shorted to the transformer core. This type of trouble can be easily located, since the resistance between any winding and the core should be very high—ten megohms or greater.

One of the most difficult types of shorts to locate is one between a number of turns in the same winding. If the normal resistance of a winding is known, its resistance can be compared with this normal resistance value. For example, if the resistance should be 100 ohms but it measures only 50 ohms, approximately half of the turns are shorted together. On the other hand, if the normal resistance of a particular winding is small, it is very difficult to determine whether or not turns are shorted since the sensitivity of the ohmmeter is not great enough. Other useful checks will be encountered in the study of equipment that contains transformers, such as checking for the proper secondary voltages when power is being supplied to the transformer.

A-C ELECTRICAL POWER SUPPLY SYSTEM

Figure 12-6 shows the electrical schematic of an a-c electrical power supply system for a fighter type aircraft. Notice that this schematic illustrates many of the principles of a-c distribution that have been given in this chapter—the 4-wire, grounded-neutral 3-phase power source, as well as the grounded-delta 3-phase distribution system. Also, it shows how a transformer is used to supply emergency power from one system to another.

The a-c supply system (fig. 12-6) consists of the No. 1 and No. 2 inverters, the instrument power switch, the No. 1 and No. 2 inverter power circuit breakers, the No. 2 inverter control circuit breaker, and associated equipment. A power failure warning light, operated by the inverter failure warning relay, gives indications of abnormal a-c power system voltage.

The instrument power switch, located on the console, selects which inverter is to energize the a-c primary buses. The No. 2 inverter supplies 115-volt, 400-cycle, 3-phase power to the 115-volt a-c secondary buses directly. The inverter also supplies power to the 115-volt, a-c primary buses when chosen by the instrument power switch. The No. 1 inverter supplies only the 115-volt, a-c primary buses when chosen by the instrument power switch. The d-c power input to the No. 1 and No. 2 inverters is such that the No. 1 inverter can be energized by either of the three sources of d-c power—battery, generator, or external power. However, the No. 2 inverter can be energized only by the generator or external power since its control power comes from the monitored bus. The No. 2 inverter is connected so as to provide Y-matched, 3-phase power to the secondary a-c buses and radar equipment at all times. The a-c neutral is grounded in this configuration and A, B, and C phases are all above ground.

When the instrument power switch is positioned to No. 2 inverter, the primary a-c A- and C-phase buses are energized by the No. 2 inverter through the wye-delta transformer. In this case, primary a-c bus loads are delta matched with B-phase grounded. The No. 2 inverter is protected from heavy wye-delta transformer loading by the A-, B-, and C-phase

transformer fuses. Low voltage (26-volt a-c, 400-cycle, single-phase power) is supplied for navigation and engine instruments by a stepdown autotransformer which derives its power from the 115-volt a-c C-phase primary bus. The a-c power supply is protected from overload by the primary bus A- and C-phase fuses and the secondary bus A-, B-, and C-phase fuses.

TROUBLESHOOTING DISTRIBUTION SYSTEMS

The general procedures to be used in troubleshooting electrical distribution systems are presented in chapter 14 of this training course. The specific procedures to be used will depend upon the particular distribution system. In other words, a single-phase system will not be checked in the same manner as a 3-phase system. The best source of information on troubleshooting a-c distribution systems is the Maintenance Instructions Manual for the aircraft involved.

The wiring data and electrical systems sections of the manual contain information on troubleshooting. When using these sections, especially the wiring diagrams, be certain that you use the diagram that applies not only to the model and modification number of the aircraft on which you are working, but also that the aircraft's bureau number is included in the group of numbers to which the drawing pertains.

CHAPTER 13

AIRCRAFT IGNITION

RECIPROCATING ENGINE IGNITION SYSTEMS

The ignition system in an aircraft, like that in an automobile, is for the purpose of igniting the compressed mixture of fuel vapor and air in each cylinder at the correct time and in the proper order. An aircraft ignition system consists of a special type of generator called a magneto, a mechanism called a distributor, spark plugs, control switches, and wiring. The magneto provides the high voltage which forces a spark to occur in each cylinder. The magneto is timed so that the high voltage is generated to obtain a spark at the correct position of piston travel in the cylinder. The distributor routes the high voltage to the various cylinders in the proper order. The spark plug supplies the gap across which the high voltage develops the spark that ignites the fuel-air mixture. The wiring connects the units, and the switches provide a means of controlling the system.

All parts of the ignition system are enclosed in a metal covering called shielding. The shielding prevents stray electrical fields of the ignition system from interfering with radio and other equipment in the aircraft.

All naval aircraft reciprocating engines are equipped with two magnetos, each connected to its own ignition system. The two systems supply dual ignition to each engine cylinder. The use of a dual ignition system serves two purposes: (1) It increases the safety factor, and (2) it increases the engine output. If a defect in the ignition system occurs so that one of the two spark plugs in the cylinder, or one complete set of plugs, stops firing, the other plug or set of plugs will continue to provide ignition. The use of a dual-ignition system also increases engine performance over that possible with a single-ignition system by igniting the fuel-air mixture at two points in the combustion chamber, thus providing a more rapid and more complete combustion.

It should be noted that in the normal operation of the engine, the ignition system functions independently of the other electric systems of the aircraft; that is, with the engine running, the ignition system performs its functions without electrical connection to the battery-generator system. In this respect the aircraft ignition system differs from that normally found in the automobile. The integral, independent character of the aircraft ignition system gives an added reliability desirable in flight operations. Failure of the battery-generator system in flight will in no way impair the functioning of the ignition system.

In addition to the regular ignition system in the aircraft, there is an auxiliary ignition unit for starting the engine. This unit is necessary particularly in cold weather. The intensity of the magneto spark is low during the starting operation due to the comparatively slow speed of the engine. The spark intensity from the auxiliary ignition unit is independent of the engine speed so it provides high voltage to the distribution system at the time that the magneto voltage is weak. This unit is used only during the engine starting period.

Two types of ignition systems are in general use on Navy aircraft. They are the high-tension system and the low-tension system. They perform the same job, but have different characteristics. Each type is discussed.

HIGH-TENSION IGNITION SYSTEM

Naval aircraft powered by reciprocating engines are equipped largely with high-tension ignition systems. Figure 13-1 illustrates all the necessary components for a high-tension, twin-magneto ignition system for a nine-cylinder radial engine. Although the units in other installations may be arranged differently, all high-tension, dual-ignition systems include the

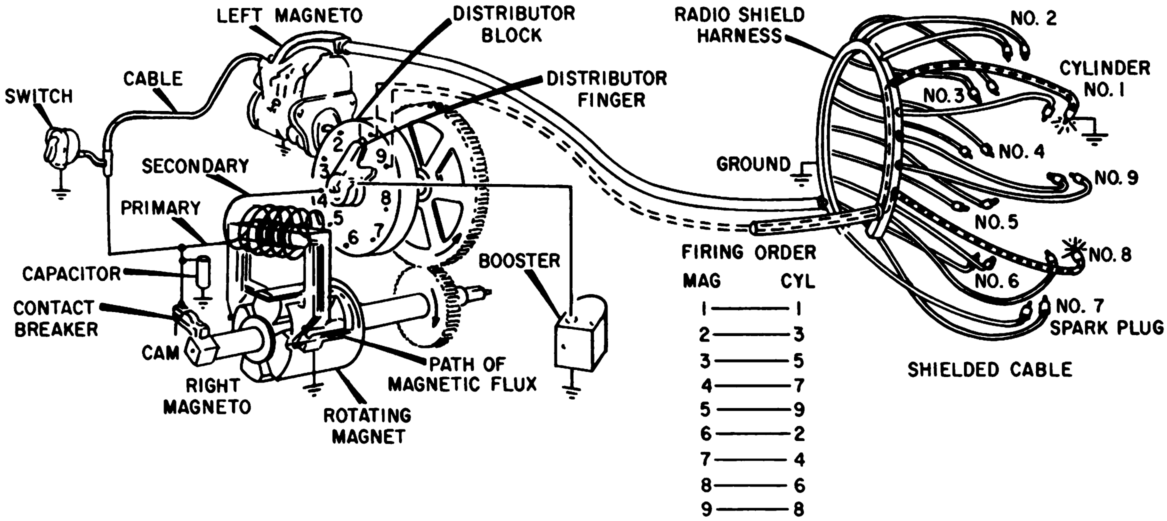


Figure 13-1.—Twin-magneto ignition system.

units shown in the illustration. The components that make up a high-tension system are:

1. TWO SEPARATE MAGNETOS. These are housed either as independent units and designated as "twin magnetos," or as a double magneto within a single case. The latter uses the same magnetic control rotor to energize its separate high voltage coils. Twin magnetos are used on some of the smaller naval aircraft engines, while all 18-cylinder engines are equipped with one double magneto.
2. TWO DISTRIBUTORS. Where twin magnetos are used, a distributor is an integral part of each magneto. On a double magneto the output coils supply voltage pulses to distributors entirely separate from the magneto. In either case, the distributors function as engine-driven rotary switches and distribute the spark impulses to the cylinders in proper sequence.
3. TWO SPARK PLUGS on each cylinder which receive current pulses from separate distributors.
4. An IGNITION HARNESS which encases the distribution circuits from the two distributors to the spark plugs.
5. Either a BOOSTER COIL or, on more current engines, a STARTING VIBRATOR, required with most magnetos for engine starting.
6. An IGNITION SWITCH.

Magneto

Prior to studying the magneto, you should review chapters 7 and 9 of Basic Electricity, NavPers 10086-A, since these chapters contain information that you must know in order to understand magneto operation.

The magneto is actually a special type of generator which uses a permanent magnet rather than an electromagnet as a field. The magnet, on rotating in the gap of an unmagnetized piece of soft iron, generates a voltage in coils wound on the soft iron. This principle is called generation of voltage by the variation of flux in a coil, and it is well to study this principle before discussing the operation of the magneto.

GENERATION OF VOLTAGE BY VARIATION OF FLUX.—To understand this principle of voltage generation, consider a permanent magnet that is free to rotate in the gap of an unmagnetized coil core and pole shoe arrangement, as shown in figure 13-2.

As the magnet is rotated, the coil core is magnetized in varying amounts. When the magnet is located at position 1, the coil core is strongly magnetized, as the magnetically opposite poles of the magnet are adjacent to the ends (pole shoes) of the coil core. The path of the magnetic lines of force is from the north pole of the magnet, through the coil core to the south pole, and then through the magnet to the north pole. As the magnet is rotated, the magnetization of the coil core decreases. At position 2, the magnetization reaches zero, since the poles of the magnet are equally distant from the shoes of the coil core, and the effect of one magnetic pole on the coil core is canceled out by the other pole. This

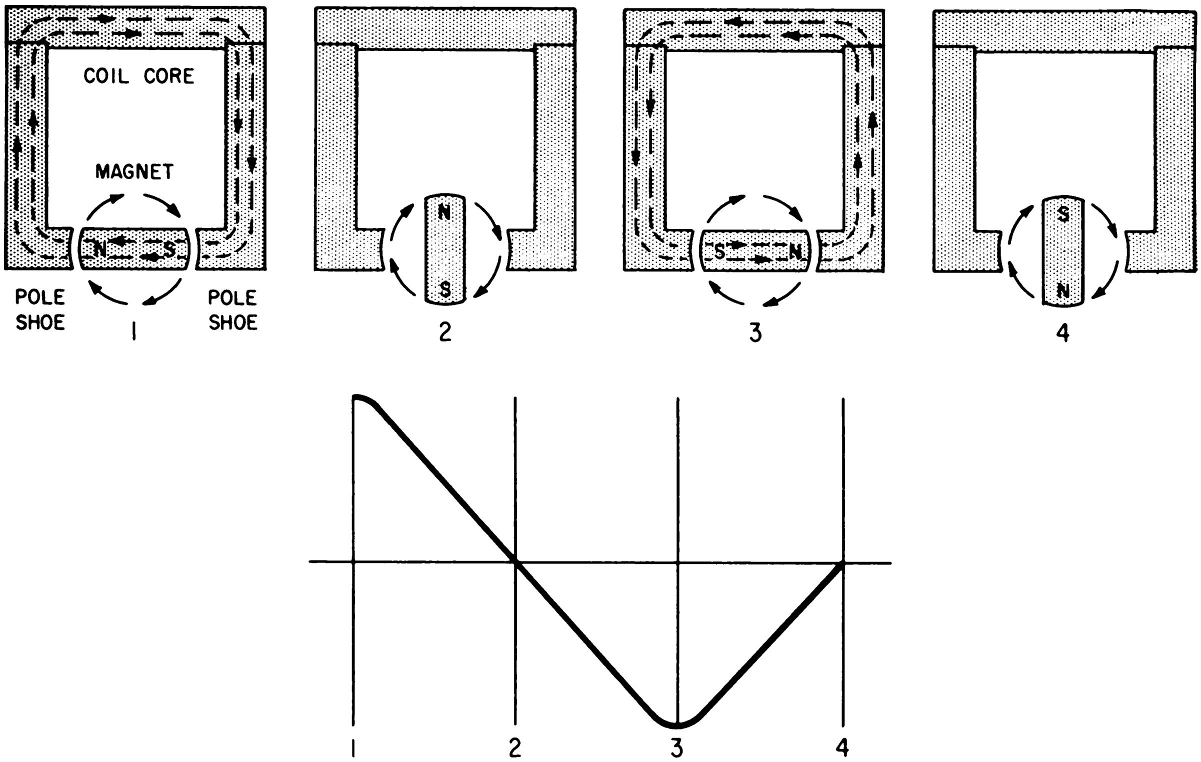


Figure 13-2.—Variation of flux in a magnetic circuit produced by a rotating magnet.

position is called the neutral position. As rotation is continued in the same direction, the magnetization of the coil core increases. At position 3, the magnetization of the coil core becomes maximum again, but the lines of force flow in the opposite direction through the coil core since the north pole and the south pole of the magnet have reversed positions with respect to the pole shoes of the coil core. Continued rotation causes a decrease in magnetization. At position 4, another neutral position is reached because of the cancellation effect between the two poles of the magnet. In one complete revolution, there are two positions of maximum magnetization of the coil core, and two positions of zero magnetization. Likewise, there are two reversals in the direction of flow of the magnetic lines of force.

Now consider the effect which the varying magnetization of the coil core has on the coil of wire wound around the core, as shown in figure 13-3. Since the coil is located in a varying magnetic field, a voltage is induced in the coil. This voltage will build up to maximum in one direction, decrease to zero, build up to maximum in the opposite direction, and again decrease to zero. As this induced voltage is changing both in direction and in magnitude, it is called alternating-current voltage. The induced voltage does not directly follow the rise and fall of the magnetization of the iron coil core, since it is zero when the magnetization of the coil core is maximum, and maximum when the magnetization is zero. The value of the voltage induced in the coil depends on the number of turns of wire in the coil, the strength of the magnet, and the speed at which the magnet rotates.

With some modifications and additions of electrical components, the simple generator just described can be made into a magneto. (See fig. 13-4.) The pole pieces of the soft iron core are so spaced that they always match two magnetically opposite poles of the rotating magnet; that is, when a north pole is opposite one pole piece, the south pole is opposite the other. Instead of a single coil wound on the core, there are two coils. One coil, called the primary, has about 150 turns. The other coil, called the secondary, contains several thousand turns. One end of the primary coil is grounded. The other end is connected to ground through a pair of

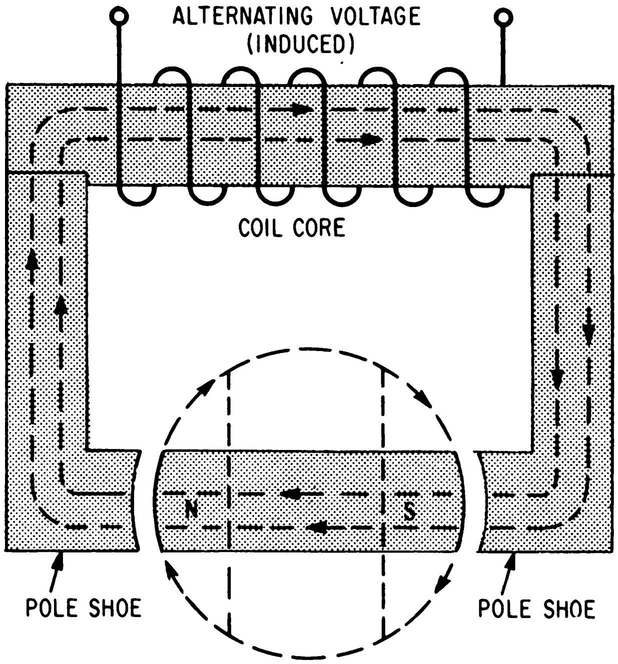


Figure 13-3.—Inducing alternating voltage.

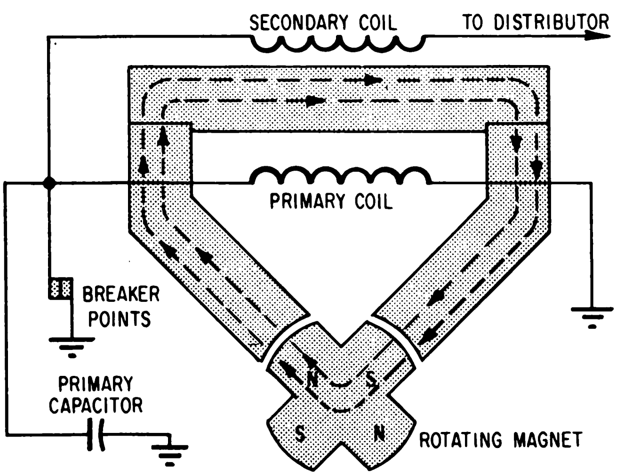


Figure 13-4.—Essential parts of a magneto.

breaker contact points which are normally held together by a spring. When the breaker points are closed, the primary circuit is complete. Across the breaker points there is a capacitor, called the primary capacitor. One end of the secondary coil is grounded, and the other end is connected to the distributor.

Figure 13-5 shows a magneto system for a single engine. Note that there are two magnetos. One is disassembled showing the parts. Included in the magneto unit are the rotating permanent magnet, called the rotor; the iron core and pole shoe arrangement in which the rotor turns; the coils, called the coil assembly; the breaker assembly, consisting of the contact points and the cam on the end of the rotor shaft; the primary capacitor; and the distributor. Other parts shown, not in the magneto but part of the system, are the ignition switch, the spark plug, wiring, and the starting vibrator.

OPERATION OF THE MAGNETO.—When the rotor in the four-pole magneto rotates (fig. 13-5), a varying amount of magnetic flux is set up in the coil core, depending on its position. At the position marked 0° of rotation (fig. 13-6), the magnetic flux is maximum, since two magnetically opposite poles are adjacent to the pole pieces of the coil core. Note that the flux movement is toward the right through the core in the 0° position. As the rotor is turned in a clockwise direction, the flux in the core decreases and finally reaches zero in the 45° or neutral position. Further rotation causes an increase in flux through the core, but note in the 90° position that the flux is now in the opposite direction. This is because the north pole of the rotating magnet is affecting the right pole shoe instead of the left as was the case in the 0° position. At the 90° position, flux is maximum, but with an additional 45° of rotation, the flux again drops to zero. It is apparent that in one complete revolution of the rotor, there would be four positions of the magnet where the magnetic flux in the coil core would be maximum and four where it would be zero.

This varying flux in the core induces an alternating voltage in the primary coil of the magneto. An alternating voltage is likewise induced into the secondary winding, but neither this voltage nor that induced in the primary is high enough to cause a spark to jump in the spark plug.

Voltage high enough to fire the spark plugs is due to the action of the primary and secondary windings and of the breaker assembly. Voltage is induced in the primary at the time the breaker points are closed. However, when the current resulting from the induced voltage in the primary reaches a maximum value, the breaker cam mounted on the rotor shaft reaches a point in its rotation where it causes the breaker contacts to open. When they open, the electric current in the

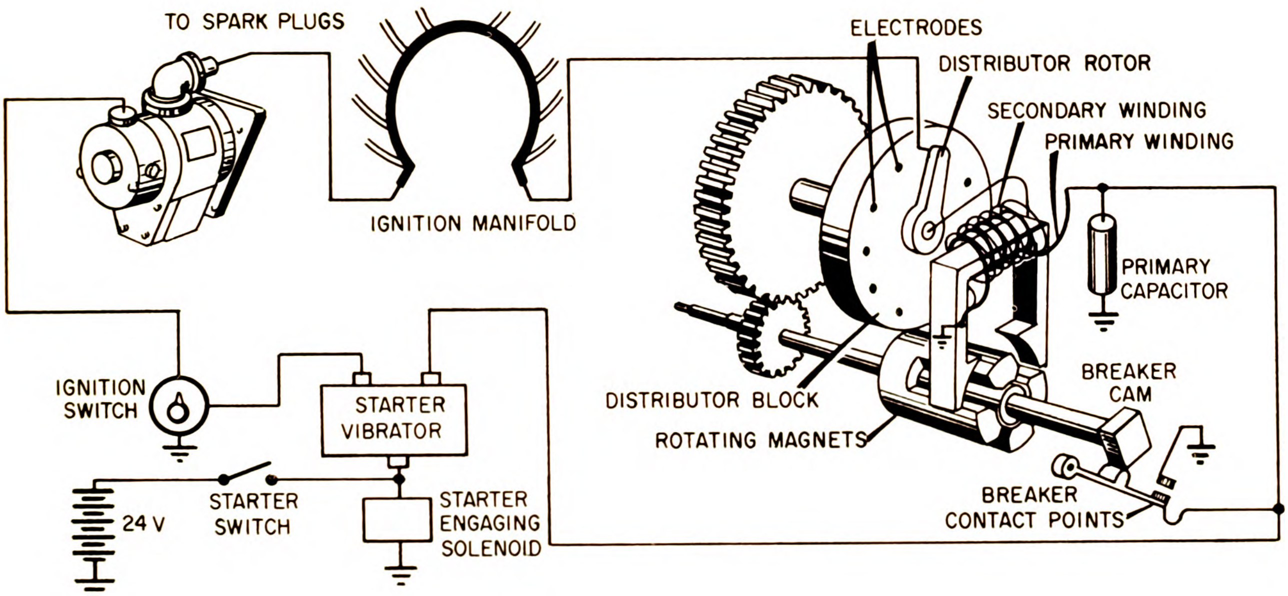


Figure 13-5.—Single-engine magneto system.

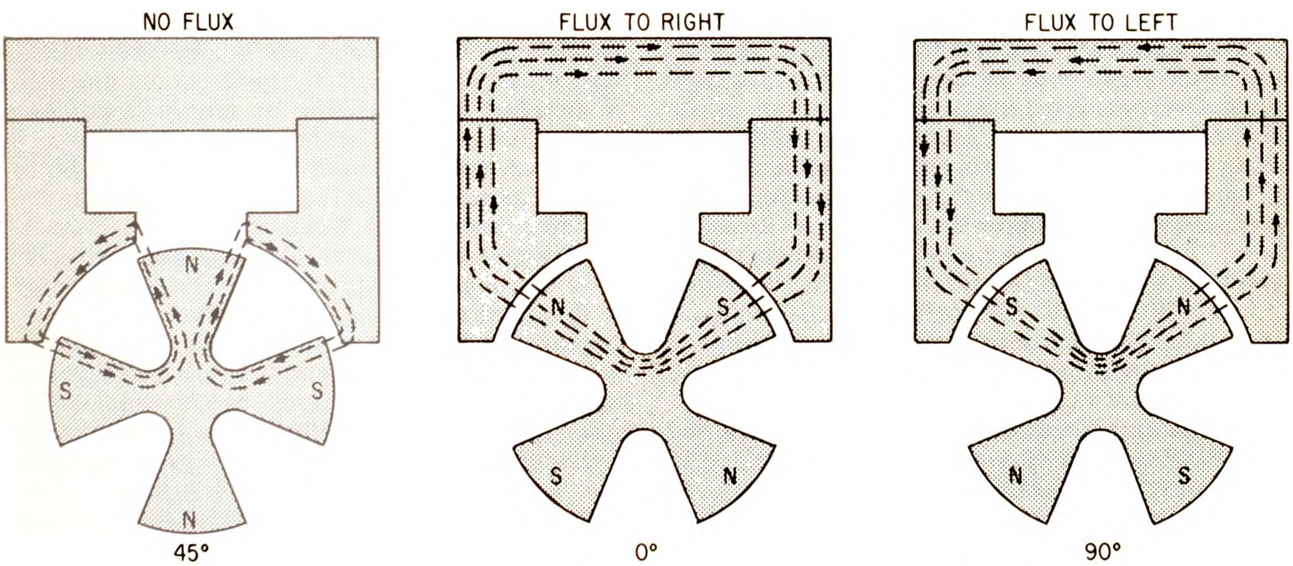


Figure 13-6.—Magnetic flux at three positions of the magnetic rotor.

primary coil is suddenly stopped. The magnetic field set up by current flowing in the primary coil suddenly collapses, and in doing so induces a voltage in the secondary winding. Since there are many more turns of wire on the secondary than on the primary, the voltage developed in the secondary is higher than that in the primary.

The capacitor connected across the breaker contact points in the primary circuit has a two-fold purpose—it prevents sparking across the

contact points, and hastens the collapse of the magnetic field about the primary coil. The interruption of the primary circuit always occurs at the instant the permanent magnet has reached a point a few degrees beyond a neutral position. This position is called the E-gap position.

The high voltage induced in the secondary winding is applied to the distributor, and thence to the spark plugs, through the high-tension ignition wiring.

MAGNETO CONSTRUCTION.—The magneto is divided into a number of parts. These are the magnetic circuit, the coil assembly, the breaker assembly, and capacitors. Although magnetos vary somewhat, all have essentially the same construction.

The MAGNETIC CIRCUIT of the magneto consists of the magnet, the pole shoes, and the coil core (the part referred to as the soft iron yoke). The magnets are made of alnico, an alloy which will retain magnetism over a long period of time. The pole shoes and coil core are laminated soft iron. In some magnetos the magnets rotate; in others, the magnets are stationary, and a soft iron rotor, called an inductor rotor, rotates between the pole shoes.

The COIL ASSEMBLY consists of the primary and secondary coils. The coil unit is covered with a case of hard rubber, bakelite, or varnished cambric. The ends of the core, on which the coils are wound, extend beyond either end of the coil assembly and are fastened on top of the pole shoe extensions with screws and clamps. The grounded end of the primary is connected to the iron core; the other, to the ungrounded breaker point. The ungrounded end of the secondary is electrically connected to the distributor rotor.

The BREAKER ASSEMBLY contains a pair of breaker contact points, made of an alloy which resists pitting and burning, and a cam. One breaker point is movable. The other is stationary. The movable breaker point is insulated from the magneto housing and is connected to one end of the primary coil. The stationary breaker point is grounded to the magneto housing. It can be adjusted so that the points will open at the proper time. The points are held closed by a spring.

The cam is mounted on the rotor shaft of the magneto. The cam may have a number of lobes (projecting parts of the cam wheel). On most radial type engines, compensated cams (cams on which the lobes are machined at unequal intervals) are used. The cams are machined this way to compensate for the top-dead-center variation of each piston due to engine design. Uncompensated cams usually have two, four, or eight lobes.

On the breaker assembly there is a fiber block, called a cam follower, which rides on the surface of the cam and forces the movable breaker point away from the stationary breaker point each time a lobe passes under the cam follower. A felt oil pad which rides on the cam provides it with lubrication.

The primary capacitor is mounted in the breaker assembly, either on top of the coil or within the coil. It may be any one of several different shapes—round, flat, or square.

MAGNETO TYPES.—Magnetos are built in single and double types. The double type consists of two magnetos using but one rotating magnet or inductor rotor. When single magnetos are used, they are called the right magneto and the left magneto, from their relative positions on the engine, as viewed from the rear of the engine. Usual practice has the right magneto to serve the front bank of spark plugs and the left magneto to serve the rear bank.

Magneto mountings are of the flange and base type, the former being used most at present. A base-mounted magneto is attached to a bracket on the engine by means of capscrews, which pass through the bracket and into tapped holes in the base of the magneto. A flange-mounted magneto is attached to the engine by means of a flange on the magneto. The holes in the flange are elongated, which permits a slight adjustment in timing the magneto to the engine by rotating the magneto before tightening the holddown nuts.

The direction of rotation of the magneto shaft is either right or left as viewed from the drive or flange end. Some magnetos have an arrow on the housing, indicating the direction of rotation.

A distributor may be built into each magneto, but on the larger engines two separate distributors are installed. This type of distributor is discussed in the following paragraphs.

Distributor

The high-voltage output from the secondary winding of the magneto is led to the distributor. As its name implies, the function of the distributor is to distribute the high voltage to a spark plug in each cylinder when that cylinder is ready to fire. The schematic drawing of a basic high-tension ignition system (fig. 13-7) illustrates the position of the distributor in the ignition system.

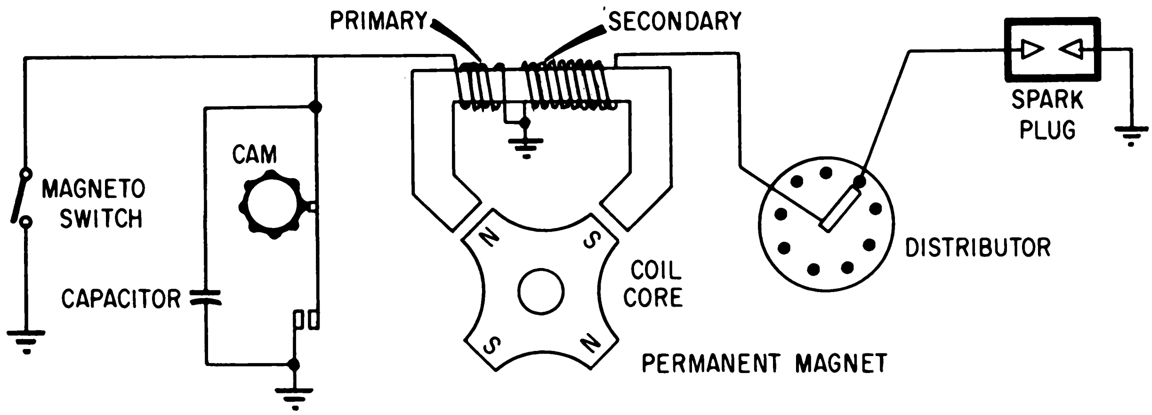


Figure 13-7.—Basic high-tension ignition system.

The high-tension current from the magneto is led to a rotating finger, or rotor, in the center of the distributor assembly. As the finger turns, the contact on its outer end completes the circuit successively through contact points having leads to one bank of plugs in the cylinders.

There is a contact for each cylinder, and the finger rotates at one-half crankshaft speed, which will give the required spark in each cylinder for every two crankshaft revolutions.

Ignition Harness

When a spark occurs in a spark gap, an electromagnetic wave, similar to a radio signal, is produced and radiated for a short distance with the ignition cable serving as an antenna. If these signals were not suppressed, they would be picked up by the aircraft's radio receiver antennas and would interfere seriously with radio reception.

In naval aircraft, every part of the ignition system that might possibly radiate electromagnetic waves—which would interfere with radio reception—is shielded completely by a metal covering. This radio shielding is grounded to the engine and picks up the undesirable radiations produced by the ignition system and carries them directly to ground, thus preventing them from reaching the receiver antennas and causing interference with reception.

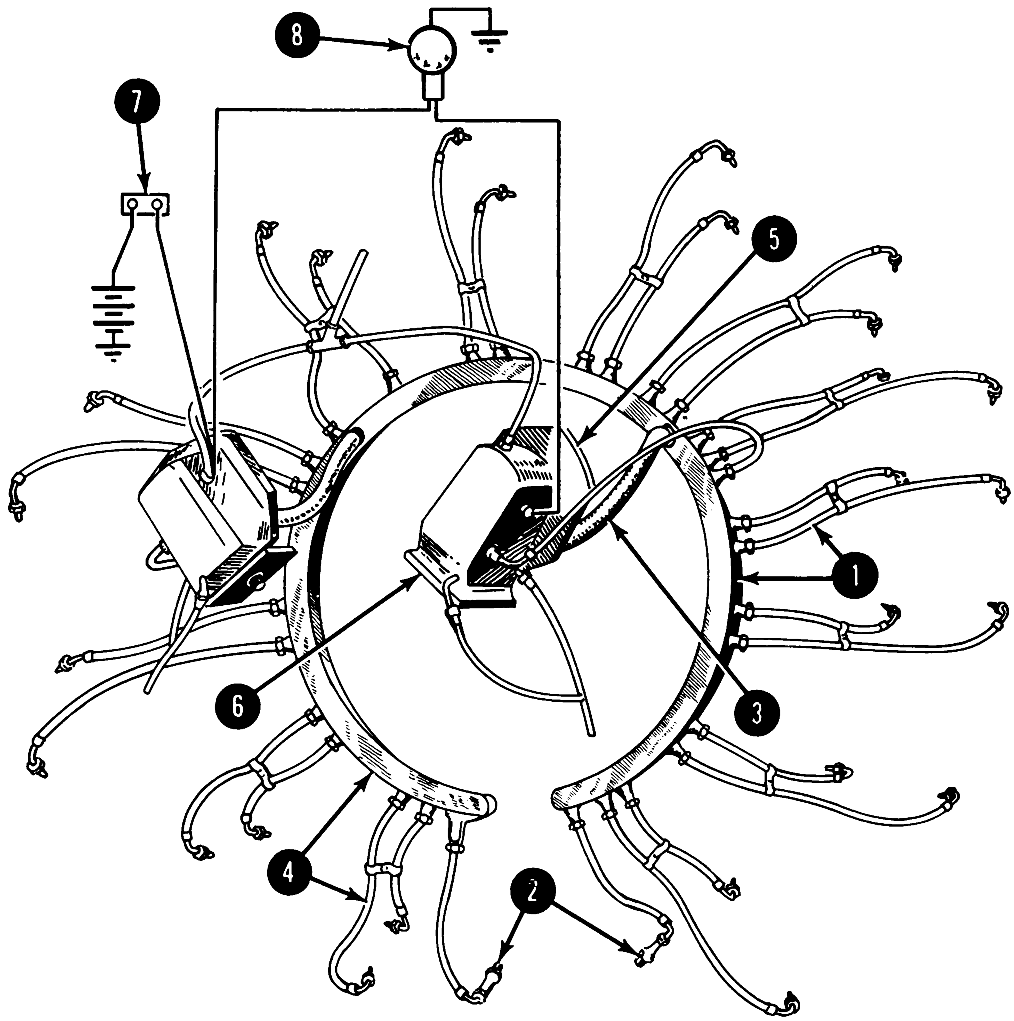
The shielding also protects the ignition cables from water and oil and from external damage.

The complete ignition wiring and shielding assembly is called the ignition harness and encases all the ignition cables installed on the engine. The ignition harness shown in figure 13-8 is composed of the following units:

1. The manifold ring, which surrounds the engine and carries the high-tension secondary cables.
2. Spark plugs and high-tension ignition cables, which extend from the manifold ring to the spark plugs and include the spark plug elbows, terminal sleeves or "cigarettes," and contact springs for attachment to the shielded spark plugs. On some of the more modern engines used by the Navy, these spark plug leads are detachable from the manifold for ease of replacement. All spark plug leads are enclosed in flexible conduits.
3. Flexible conduits extending from the distributors to the manifold ring.
4. Shielding.
5. Distributor.
6. Magneto.
7. Booster or induction vibrator.
8. Ignition switch.

The conventional type of harness ring (fig. 13-8) tends to collect moisture due to a breathing effect resulting from changes in altitude. Moisture in the manifold is not in itself detrimental to the operation of the ignition system, but may ground portions of the system if it reaches a high-tension junction point in the leads. The conventional manifold has drain holes at the bottom of the ring, but these do not prevent moisture from draining to the lower spark plug connections.

Moisture and altitude are the principal sources of ignition trouble. Moisture accumulates in various air pockets around the ignition



1. Manifold ring.
2. Spark plugs.
3. Flexible conduit.
4. Shielding.
5. Distributor
6. Magneto.
7. Booster or induction vibrator.
8. Ignition switch.

Figure 13-8.—Ignition harness.

system. This results in "flashover"; that is, the high-tension current, instead of jumping across the spark plug gap, finds a lower resistance path to ground.

The dielectric (insulating) strength of air decreases with a decrease in pressure (up to a critical point). Therefore, at high altitudes, the tendency for flashover to occur is increased, especially in the presence of moisture or of a grease or carbon residue left on the ignition parts by maintenance personnel.

Moisture and altitude difficulties have led to the development of pressurized and plastic-filled harnesses, and also to the pressurizing of magnetos and distributors, as well as to the development of low-tension ignition system. To further increase electrical security at critical places, a special ignition sealing compound is applied to various clearances and recesses in

the ignition system for the purpose of excluding air and moisture.

The electrical connections at all shielding joints, such as where the shielding of one ignition unit connects to that of another unit, must be as good as possible so that the disturbing radiations received by the shielding are grounded out.

Ignition Cable

The secondary voltage, ranging from 10,000 to 25,000 volts, must be carried from the magnetos to the spark plugs by wires properly insulated for this high potential. The type of high-tension cable in general use is constructed of 7 strands of No. 28 stainless steel wire which is encased in a molded rubber composition for insulation. The rubber insulation is protected by a fabric braid, and a coating of lacquer keeps air and moisture away from the braid. The overall diameter of the cable from the harness manifold to the spark plug is 7 millimeters.

The construction of low-tension cable is similar to that of the high-tension cable. Due to the much lower voltage carried by this cable, however, the insulation is only one thirty-second of an inch in thickness, giving an outside diameter of three-sixteenths of an inch. The wire core consists of 7 strands of 18-gage tin-plated copper wire. This wire is used in the ground circuits to the ignition switch as well as in the low-tension ignition system.

Ignition cable deteriorates rapidly. Spare ignition harnesses fabricated within the past 12 months are kept ready for use. Those of greater age are rejected for aircraft use.

Ignition harnesses while in use must be closely inspected for any deterioration in their rubber insulation. Engine heat and particularly ozone, which is generated from oxygen when close to high voltage conductors, will cause rapid rubber deterioration. The lacquer coating about the rubber must be airtight to prevent ozone contact and consequent damage. Even a slight break in the lacquer coating will eventually render the cable unfit for use in aircraft.

Ignition Switch

All units in the ignition system are controlled by a switch in the cockpit. The type of switch used varies with the type of ignition used--that is, whether it is a single-engine or a twin-engine ignition. All switches, however, turn the system off and on in much the same manner. The ignition switch is connected in parallel with the contact points in the breaker assembly so that when it is placed in the OFF position the breaker points are short circuited and the magneto is made inoperative. This occurs because the current in the primary cannot be interrupted, even though the breaker points are opened and closed. When the control switch is in the ON position, the short is removed and the ignition system is operative because the primary current can be interrupted by the breaker points.

There are four positions on an aircraft magneto switch—OFF, RIGHT, LEFT, and BOTH. One side of the switch is connected to ground. When the switch is in the OFF position, it is closed, connecting the primary windings of both magnetos to ground. When the switch is at BOTH, this circuit is open and the primary coils are no longer grounded through the switch. In the R (right) position, the primary of the left magneto is grounded; in the L (left) position, the primary of the right magneto is grounded. Therefore, when the pilot switches to R, the engine is running on the right magneto, and he can check for normal operation of the right magneto. With the switch in the L position, operation of the left magneto can be checked. An ignition switch for a single-engine aircraft is shown in figure 13-9.

An ignition switch designed for twin-engine aircraft is shown in figure 13-10. This switch combines two switches of the type shown in figure 13-9, with the addition of a push-pull knob which operates the master emergency ignition switch. When the knob is pulled out to the OFF position, all ignition is cut off regardless of the position of the switch levers. In an emergency, all ignition for both engines can be cut off by one movement of the push-pull knob to the OFF position.

When switching from BOTH to either R or L, normal operation is indicated by a loss of engine rpm. The amount of drop to be expected varies with the engine and the allowable maximum drop can usually be found in the operating manual of the engine concerned. If no drop in rpm occurs, it indicates that the primary coil of the magneto is not being grounded. This is a dangerous condition, because the pilot would no longer have positive control of the magnetos. This would be of particular importance in an emergency when the pilot would have to cut the ignition, as in a crash landing. It is also dangerous even with the engine not running, as anyone moving the propeller would be exposed to the danger of the engine

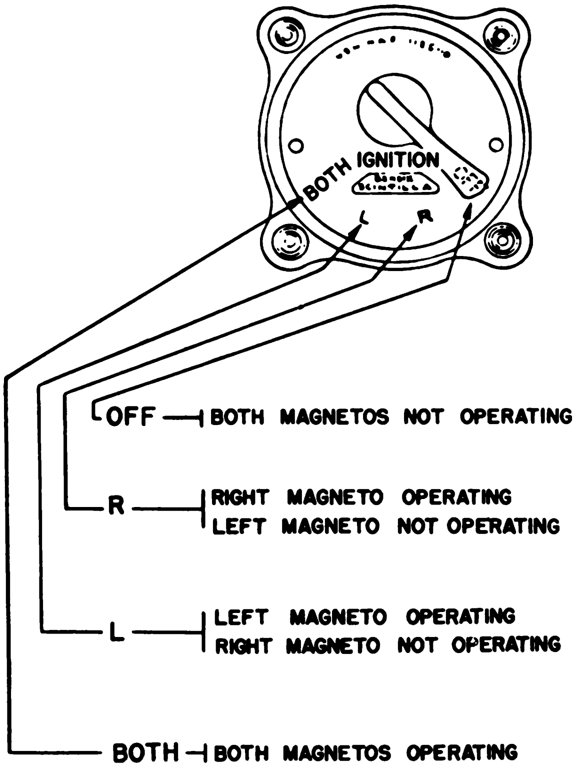


Figure 13-9.—Single-engine ignition switch.

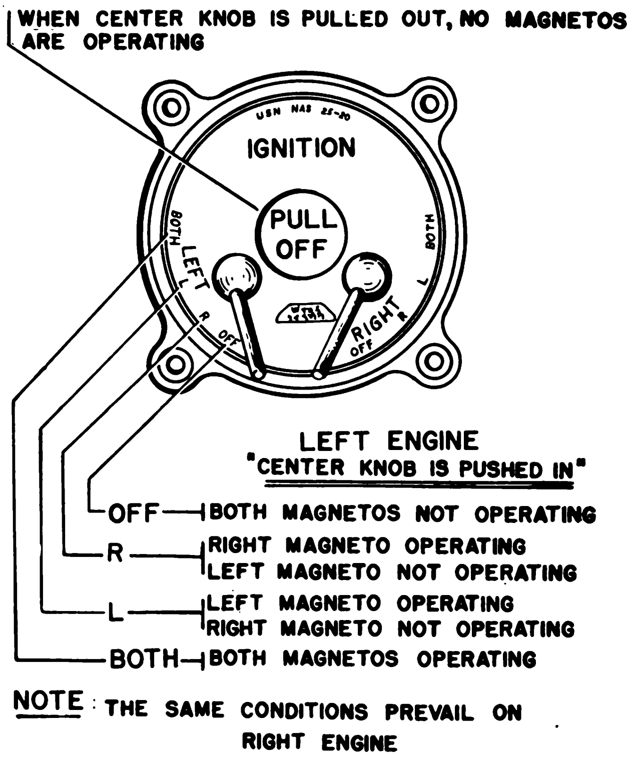


Figure 13-10.—Twin-engine ignition switch.

kicking over, since one magneto is still ON. Although all Navy piston-engined aircraft have some form of idle cutoff system in the carburetor, it is very important that the switch be capable of grounding the magnetos.

Spark Plugs

The function of the spark plug is to provide a small airgap in the cylinder across which the magneto secondary current is forced to jump, thereby igniting the compressed fuel charge in the cylinder.

Spark plugs are frequently classified in accordance with the insulation used. Presently, the Navy uses only ceramic type plugs.

A cross sectional view of a typical spark plug is shown in figure 13-11.

The lower end of the shell carries the threads that screw into the cylinder head and also includes the hexagon-shaped section which fits into the spark plug socket wrench. The ground electrode is attached to the lower end of the shell. This ground electrode forms one side of the spark plug gap and is connected to the ground side of the electric circuit through the threads of the shell. The aircraft engine, and consequently the cylinder head, is at ground potential. Inside the shell is the core insulator and a seal, which prevent leakage of the combustion gases. Heat generated at the spark plug gap is conducted away through the shell to the cylinder head.

The core insulator consists of a body of nonconducting ceramic material which contains the center electrode. The lower end of the center electrode is the other side of the spark gap. The upper end of the center electrode is in contact with the high-voltage circuit to the distributor. A resistor is a sealed-in part of this center electrode to minimize erosion of the spark electrodes.

The shielding barrel protects the radio and other electronic equipment from interference set up by the sparking at the spark plug gap. The barrel contains an insulating sleeve to insulate it from the center electrode side of the spark gap. The upper end of the barrel is

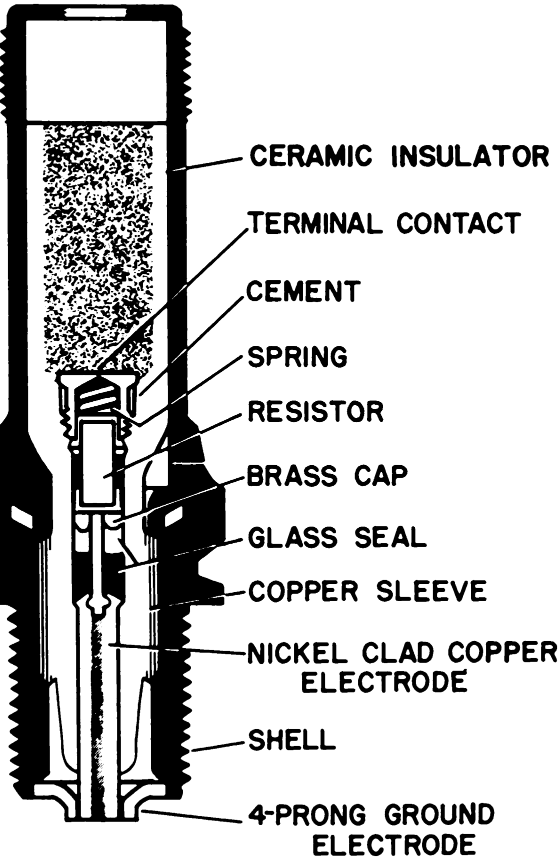


Figure 13-11.—Cross sectional view of a spark plug.

threaded for attachment of the high-voltage cable elbow.

The distance that the spark plug extends into the cylinder is determined by the length of the threaded portion of the plug. This is called the reach. Different manufacturers design plugs with different amounts of reach. Some are recommended for a certain aircraft and others are recommended for a different type of aircraft.

A spark plug that operates at a relatively high temperature is called a hot plug. It is a hot plug because of its design. The amount of material in the electrodes and associated parts of the plug is small so that there is not a very effective heat path away from the electrodes. A plug that remains relatively cool in the cylinder is called a cold plug. This type of plug has a better heat path leading away from the electrodes than the hot plug. The type of spark plug that is used is specified by the engine manufacturer. Some engines run better with hot plugs, while others run better with cold plugs.

LOW-TENSION IGNITION SYSTEM

The low-tension ignition system is designed to reduce the tendency toward flashover, or shorting, of high-tension current because of low atmospheric pressure at high altitudes, or because of moisture from condensation. In the low-tension system, separate high-tension coils for each cylinder are located on the cylinder, reducing the length of the high-tension leads, thus reducing the electrical losses and possibility of flashover usually found in long high-tension cables. A basic low-tension ignition system is shown schematically in figure 13-12.

In the figure 13-12, it should be noted that the circuits carrying high-voltage current are very short. With low-tension current flowing through the distributor and most of the harness, the possibility of flashover in the harness, particularly when operating at high altitudes, is practically eliminated. Spark plug erosion is also reduced because of reduced buildup of high voltage in long high-tension leads due to capacitance between the high-tension cables and the shielding.

The low-tension magneto, sometimes called a magneto generator, produces low-tension or primary current only. The current is distributed to two separately mounted distributors, which also operated in the low tension circuit. As noted in figure 13-12, these distributors (only one is shown) contain the breaker point assemblies as well as the distributor rotors and segments. From the distributors, the primary current is delivered through a low-tension harness to separate high-tension induction coils, one of which is provided for each spark plug.

The low-tension magneto, shown in figure 13-13, produces only primary current. This primary current is distributed, as shown in figure 13-14, through the primary leads to the separate low-tension distributor and breaker points, which are housed in the distributors. For the low-tension distributors, the current is delivered through a low-tension harness to separate high-tension induction coils provided for each spark plug.

The low-tension magneto consists of two 4-pole rotating magnets, four primary coils, connector plugs for making the primary connections from the primary coils to the distributor

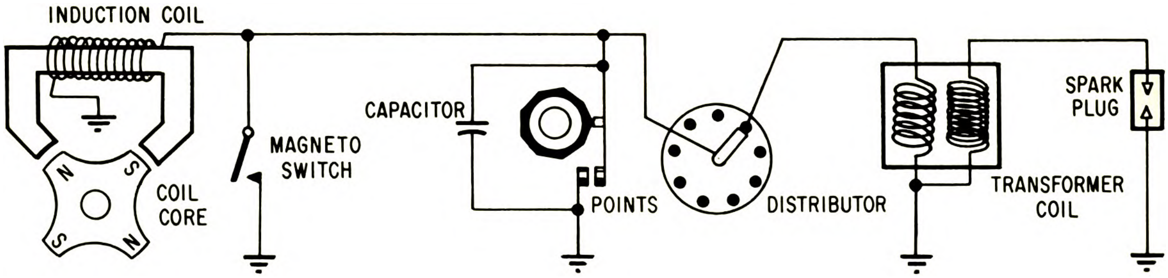


Figure 13-12.—Basic low-tension ignition system.

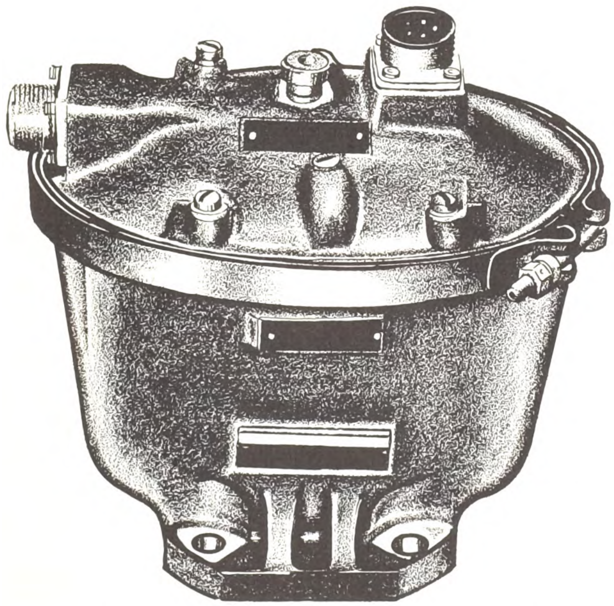


Figure 13-13.—Low-tension magneto.

units, the ground switch (ignition switch), and the primary booster or starting vibrator lead.

Each high-tension induction coil assembly contains two separate coils, which serve the front and rear spark plugs in the cylinder. Short, shielded high-tension leads carry the high-voltage current from the coil assemblies to the spark plugs.

AUXILIARY IGNITION STARTING SYSTEMS

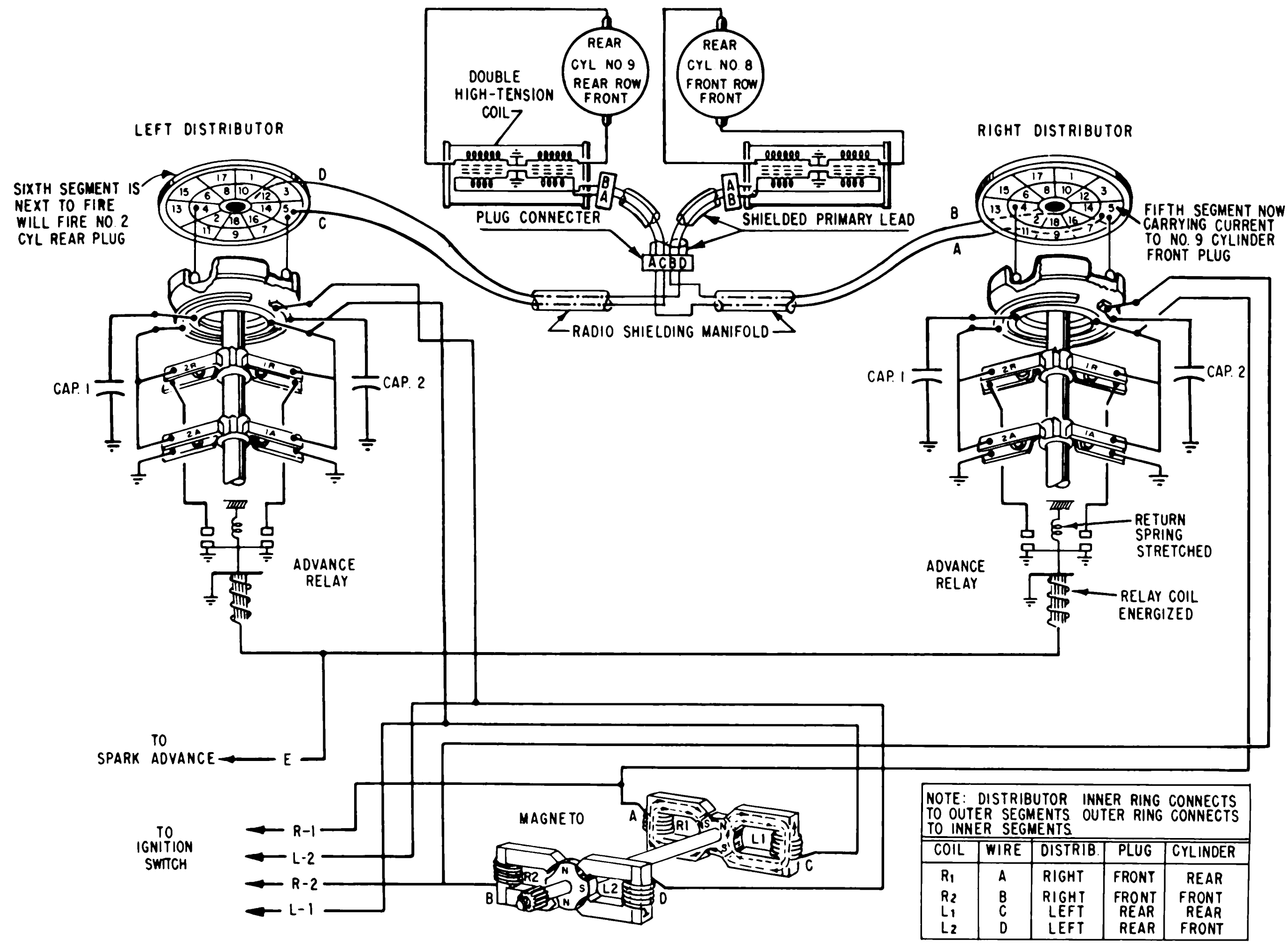
When turning the engine with the starter in the starting operation, the speed of rotation of the magneto is too low to produce sufficient voltage at the spark plug electrodes. The coming-in speed for magnetos is around 100 rpm of the rotating magnet or armature. Therefore, special provision must be made to supply the required spark plug voltage for starting. The two most common devices used are called the booster coil and the starting vibrator.

Booster Coil

The booster coil is used to develop a good hot spark when the engine is being started. A typical booster-coil circuit is shown in figure 13-15.

The booster coil receives low voltage power from the aircraft battery and delivers high-voltage power to the ignition system. When the starter switch is closed, battery current flows through the primary coil, the iron core becomes magnetized, and when the magnetism is strong enough to overcome the tension of the spring which holds the contact points closed, the points open and the magnetic field about the iron core collapses. The rapid collapse of the magnetic field induces a high voltage in the secondary.

When the core loses its magnetism, the contact points close, battery current again flows in the primary, and the process is repeated. The contact points open and close rapidly, automatically breaking and completing the primary circuit as long as battery power is applied to the booster coil. The secondary output of the booster coil is connected to the distributor. Distributors used with booster coils have two distributing fingers on the distributor rotor; the leading finger distributes the high voltage generated by the magneto, and the trailing finger distributes the high voltage from the booster coil to the spark plugs.



COIL	WIRE	DISTRIB.	PLUG	CYLINDER
R_1	A	RIGHT	FRONT	REAR
R_2	B	RIGHT	FRONT	FRONT
L_1	C	LEFT	REAR	REAR
L_2	D	LEFT	REAR	FRONT

Figure 13-14.—Low-tension ignition system.

The trailing finger is so located that it automatically retards the spark from the booster coil. This lessens the danger of "kickback" during engine starting. The operation of the booster coil is controlled by a switch which may also control some other function such as cranking or engagement of the aircraft's starter.

Starting Vibrator

Figure 13-16 illustrates a starting-vibrator circuit. The starting-vibrator unit is composed of a relay and a vibrator. The function of the unit is to deliver a pulsating direct current to the primary winding of the magneto coil. Through transformer action, a high voltage is produced in the magneto secondary coil when the primary is pulsed. The resulting high-tension current is distributed to the spark plugs just as during normal operation.

With the ignition switch open and the starter switch closed, battery power is fed to the starting vibrator unit. This power energizes the relay coil, which causes the normally open relay points to close. The relay points complete the circuit through the magneto, and the vibrator begins to operate.

As soon as the vibrator coil becomes energized, its magnetized core overcomes the spring tension, thus opening the normally closed contacts. This breaks the circuit deenergizing the vibrator coil, and the points return to the closed position. Closing of the points again energizes the vibrator coil and causes the points to open. This automatic opening and closing of the vibrator points produces pulsating direct current which flows to the primary winding of the magneto when the relay coil is energized.

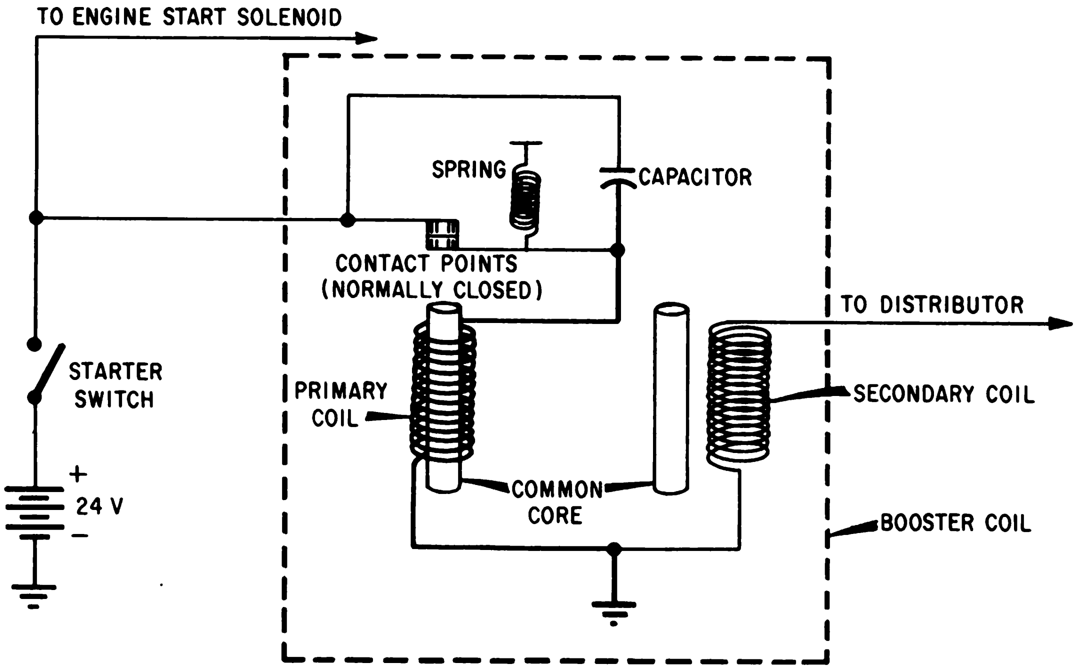


Figure 13-15.—Booster-coil circuit.

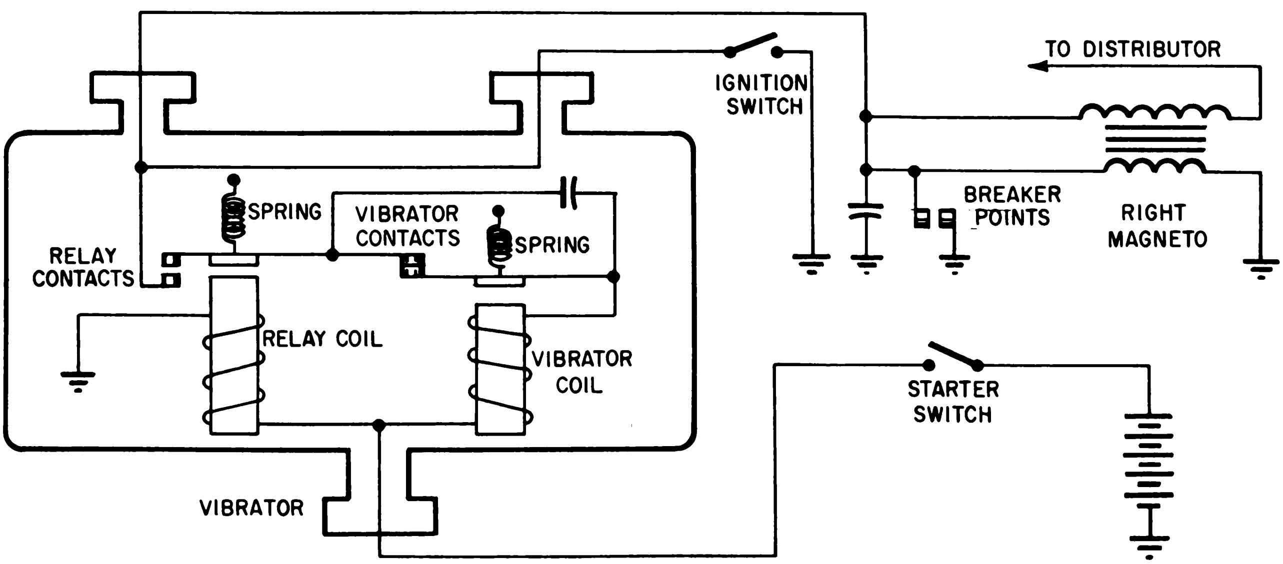


Figure 13-16.—Starting-vibrator circuit.

JET ENGINE IGNITION SYSTEMS

ELECTRONIC IGNITION SYSTEM

This type system is used for providing internal combustion for turboprop and turbojet engines. The ignition system is required only for starting the engine; once combustion has begun, the flame is continuous. Figure 13-17 shows the components of a typical electronic ignition system.

The electronic turbo ignition system (fig. 13-17), consists of a dynamotor-regulator-filter assembly, an exciter unit, two high-tension transformer units, two high-tension leads, and two igniter plugs, together with the necessary interconnecting cables, leads, control switches, and associated equipment as required for operation in an aircraft.

The dynamotor is used to step up the direct current of the aircraft battery or the external power supply to the operating voltage of the exciter unit. This voltage is used to charge two capacitors which store the energy to be used for ignition purposes.

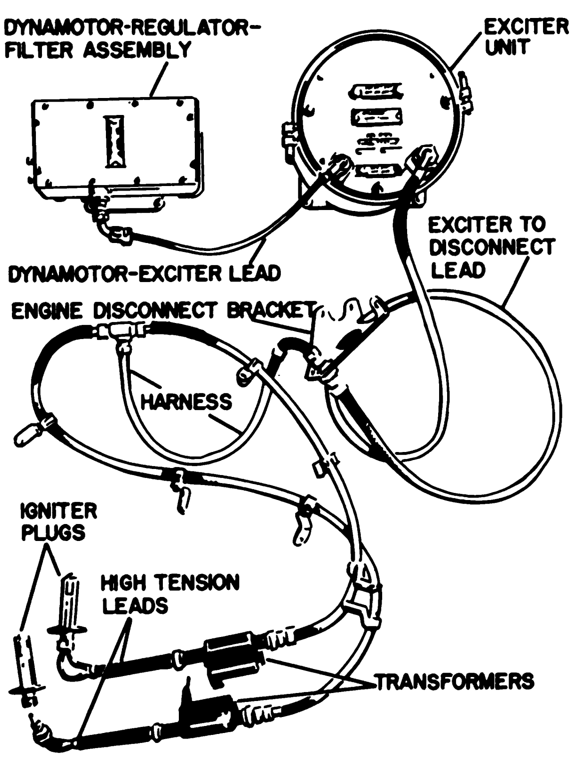


Figure 13-17.—Electronic ignition system.

In this system the energy required to fire the igniter plug in the engine burner is not stored in an inductor coil as in conventional types of igniters. Instead, the energy is stored in capacitors. Each discharge circuit incorporates two storage capacitors; these are located in the exciter unit. The discharge of the smaller capacitor, sufficiently stepped up by the transformer unit, breaks down the airgap at the plug. At this instant, the resistance of the gap is lowered sufficiently to permit the larger capacitor to discharge across the gap. The discharge of the second capacitor is of a low voltage but of very high energy. The result is a spark of great heat intensity, capable not only of igniting abnormal fuel mixtures but also of burning away any foreign deposits on the plug electrodes.

The exciter is a dual unit, and produces sparks at each of the two igniter plugs. A continuous series of sparks is produced until the engine starts. The batter current is then cut off and the plugs do not fire while the engine is operating.

The igniter plugs are, in general, similar to the spark plugs used on reciprocating engines except for such changes as are necessitated by the higher energies, voltages, and temperatures encountered in jet operation. In general, the igniter plug is larger, more open in construction, and is set to a much wider gap than the spark plugs of familiar design. Figure 13-18 shows a typical jet igniter plug.

CAPACITOR-DISCHARGE IGNITION

This type of ignition system is for starting jet aircraft. Figure 13-19 shows a typical capacitor-discharge electronic ignition system.

The ignition system comprises three major components: one ignition exciter and two lead assemblies. The exciter unit is hermetically sealed. This affords permanent protection to the internal components from moisture, foreign matter, inadvertent maladjustments, pressure changes and adverse operating conditions of all kinds. This type of construction eliminates the possibility of flashover at high altitude due to pressure change, and insures positive radio noise shielding. The complete system including leads and connectors is designed to insure adequate shielding against leakage of high frequency voltage interfering with the radio reception of the aircraft. It is designed to supply energy to two surface type spark igniters.

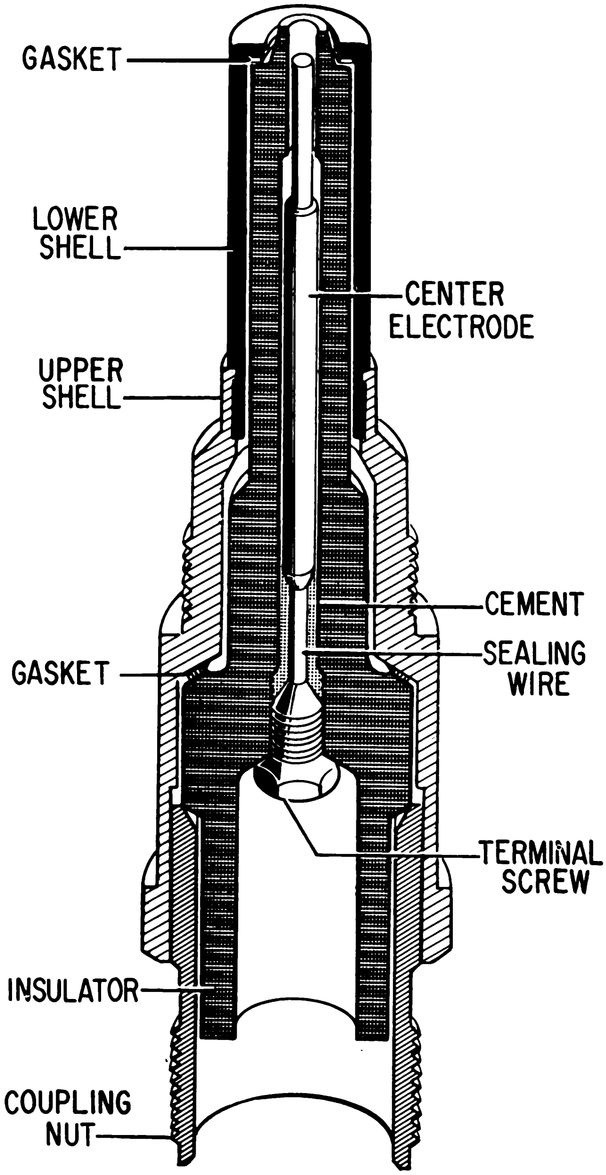


Figure 13-18.—Cross sectional view of a jet igniter plug.

Figure 13-20 is a functional schematic of the system. Refer to this figure when studying the theory of operation.

The ignition system derives its input power from the low-voltage d-c power supply of the aircraft electrical system. Its function is to produce high energy, capacitance type sparks at the spark igniters in the engine.

Input power from the low-voltage supply is fed to a d-c motor through a noise filter which drives a multilobe cam thus actuating two breakers, and a single-lobe cam which actuates two contactors. One breaker and one contactor are associated with each side of the system. The two sides are identical, and the following description applies to either side.

When the breaker is closed by the multilobe cam, input current flows through the primary winding of the autotransformer, establishing a magnetic field. The breaker is then opened, the flow of current stops, and the collapse of the field induces about 1,000 volts in the secondary. This voltage causes a pulse of current to flow into the storage capacitor through a rectifier, which limits the flow to a single direction. Thus, each time the breaker opens, the capacitor receives a charge of electricity, and the action of the rectifier prevents any loss of this charge. When 34 such pulses have accumulated a charge on the capacitor, the contactor is closed by the mechanical action of the single-lobe cam, and the capacitor discharges its stored energy through

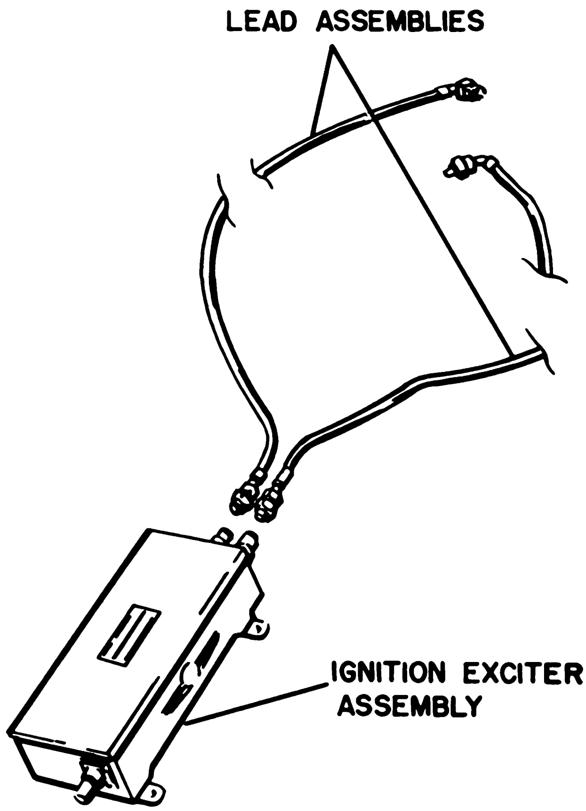


Figure 13-19.—Capacitor-discharge ignition system.

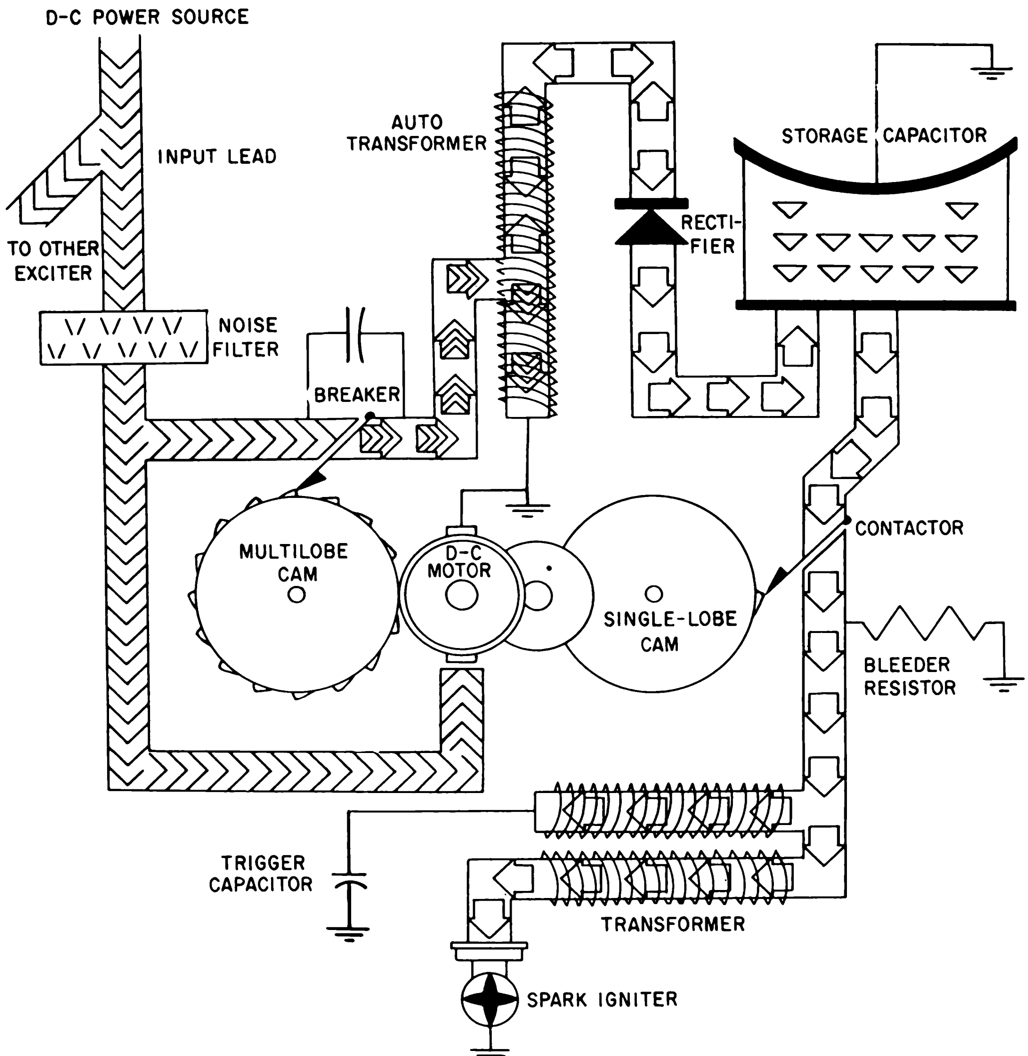


Figure 13-20.—Functional schematic of capacitor-discharge igniter.

a triggering transformer and is dissipated at the spark igniter. The triggering transformer action is similar to the booster transformer discussed later in this chapter.

The spark rate at the plug will vary in proportion to the voltage of the d-c power supply, which affects the speed of the motor. However, since both cams are geared to the same shaft, the storage capacitor always accumulates its store of energy from the same number of pulses before discharge.

CAUTION: Due to the high voltage and amperage of this system, extreme care should be used around the equipment.

TYPICAL JET IGNITION SYSTEM

With the development of modern, powerful jet engines for the Navy's first line aircraft, the demand for a reliable, maintenance free ignition has become more acute. No attempt is made in this chapter to cover all of the systems utilized; however, a typical jet ignition system is discussed. The system discussed is similar to the system used in the F-4B aircraft.

Engine Ignition

The ignition system produces sparks which ignite the fuel-air mixture in the combustion

chamber of a jet aircraft engine. The closing of the ignition switch completes the electrical path from the aircraft power supply, thus energizing the ignition system. The power supply for this system is alternating current. The a-c voltage is fed to the ignition unit where it is stepped up and then rectified. The resultant current charges a tank capacitor. A sealed airgap in the main ignition unit triggers the periodic discharge of the capacitor. Each time the capacitor discharges, a large surge of energy is transmitted through the spark plug lead to the main spark plug.

Normally, a potential of approximately 1,000 volts between the electrodes is sufficient to ionize the airgap. The ionized airgap allows current to flow across the airgap, furnishing a low-impedence path through which the tank capacitor can discharge. This discharge produces a high-energy spark that ignites the fuel-air mixture in the combustion chamber. Once ignition has been accomplished, combustion continues without further sparking. The main ignition system is shut off after the engine has been started.

Components of the main ignition unit change the amplitude and the frequency of the aircraft current into a pulsating d-c voltage of approximately 3,000 volts at discharge. Figure 13-21 is a schematic of the main ignition unit used in a late model aircraft. The components are grouped into stages to filter, amplify, rectify, and store a high-voltage charge. The charge is then discharged in pulses to the main ignition spark plugs. The ignition unit discharges approximately two times a second.

A pi-type filter, consisting of C1, L1, and C2 (fig. 13-21), and located in the input stage of the ignition unit, grounds out radiofrequency interference entering or leaving the unit. This prevents the ignition unit from affecting the operation of the aircraft's avionic equipment. The choke coil L1 blocks RF current flow in either direction, and the two capacitors, C1 and C2, act as short circuits to ground for RF. Thus, radiofrequency noise pulses approaching the filter from either direction are blocked by the coil and shunted to ground by the capacitors. However, choke coil L1 easily passes current from the aircraft power source, and capacitors C1 and C2 present a high impedance to ground for the 400 cps supply.

The opposition of the choke coil and the capacitors to current flow differs because their reactance changes when frequency is altered. At radiofrequency, inductive reactance of the coil is high and capacitive reactance of the capacitors is low. At lower frequencies, the opposite condition exists.

When power is applied to the igniton unit, on one-half cycle current flows from ground through the transformer primary winding L2, the radiofrequency filter, and back to the power source. Current through the transformer primary winding induces an a-c voltage in the transformer secondary winding L3. The secondary winding voltage is much higher than the 115-volt ignition unit input. The output of the transformer charges the storage (tank) capacitor C4 by means of a half-wave voltage doubling circuit. Capacitor C3 limits the charging rate (hence, the spark rate) of the tank capacitor C4.

During one half-cycle when the bottom of L3 is positive with respect to the top, electrons leave the right plate of C3 and flow through V2, V4, and R1 to ground, thus charging C3. This action produces a positive potential on the right side of C3 with respect to the left side. The magnitude of this potential is approximately the same as that appearing across L3.

On the alternate half-cycle when L3 is positive at the top with respect to the bottom, V1 and V3 provide a path for C3 to discharge itself to C4. However, the potential across C3 is in series with that across L3. Thus, the potential impressed on C4 during this half-cycle is approximately twice that appearing across the secondary winding L3.

The voltage across capacitor C4 increases until it is equal to the breakdown level of gap G1. The sealed airgap G1 ionizes at approximately 3,000 volts. When this voltage across C4 is reached, the sealed airgap G1 provides a low-impedance path for C4 to discharge across the spark plugs.

R1 is a current-limiting resistor which prevents a high surge current from damaging the rectifiers when capacitor C3 starts to charge. Resistor R2 functions as a safety bleeder resistor. It acts as a dummy load if the ignition unit is energized while the spark plugs are disconnected. This eliminates possibility of damage to the ignition unit.

CAUTION: The main ignition units contain radioactive material within the sealed airgap. This material is dangerous if the sealed airgap is broken.

BOOSTER TRANSFORMER.—Some main ignition units also use a booster transformer connected as depicted in figure 13-21. The booster transformer, when necessary, increases

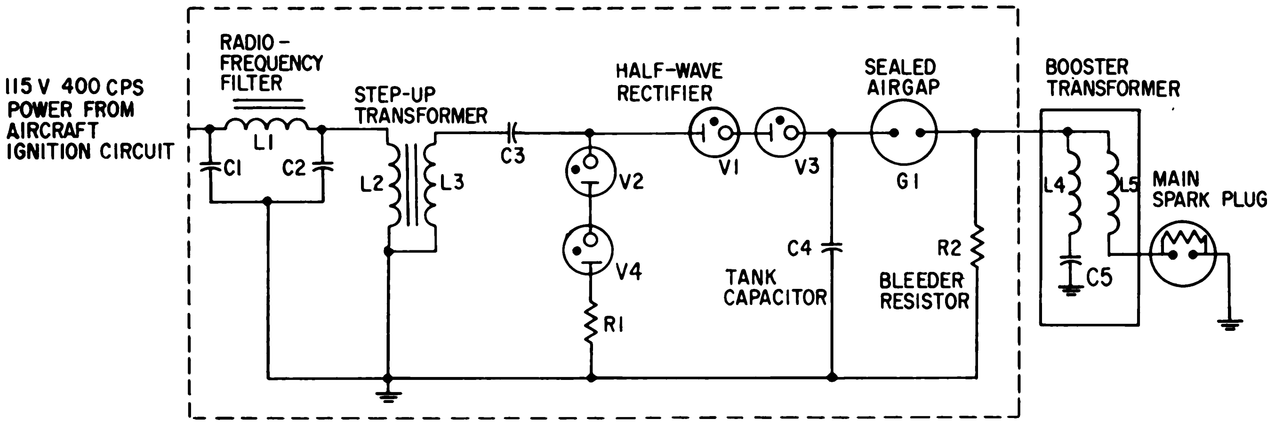


Figure 13-21.—Schematic of a main ignition unit.

the output voltage of the ignition unit and thus insures the reliability of the system.

Normally, the sealed airgap G1 and the spark plug electrode gap ionize, allowing the tank capacitor to discharge across the electrodes. If the output voltage of the ignition unit is insufficient to ionize the gap between the spark electrodes, the booster transformer steps up the output voltage, insuring ionization of the spark plug electrode gap.

Current flows across the ionized gap G1 and the primary winding L4, charging capacitor C5. The flow of current through the primary winding L4 induces a high voltage in the secondary winding L5. This secondary voltage may be as high as 12,000 volts. When the potential is sufficiently high, the spark electrode gap ionizes and the tank capacitor discharges across the electrodes. Capacitor C5 discharges through R2 to ground between sparks after the burner ignites.

AFTERBURNER IGNITION.—The afterburner ignition system is activated by the ignition contacts of the afterburner ignition switch. When the afterburner fuel pump discharge pressure reaches a preset value (approximately 150-190 psi), the switch contacts close to complete the circuit from the aircraft power supply to the afterburner ignition unit. The supply voltage is stepped up by a transformer and rectified in the ignition unit. The rectified voltage is used to charge a tank capacitor. Figure 13-22 is a schematic diagram of the afterburner ignition unit.

A sealed airgap in the ignition unit triggers the periodic discharge of the capacitor three to six times a second. Each time the capacitor discharges, a large surge of energy is transmitted through spark electrode leads to the afterburner spark plug.

The components in the afterburner ignition unit convert the 400 cps a.c. from the aircraft power supply into pulsating d.c. These components are grouped in separate stages to filter, amplify, rectify, and store an electrical charge, which is then discharged across the electrodes of the afterburner ignition. The afterburner ignition circuit is depicted in figure 13-22. The circuit is similar to the main ignition circuit. A comparison of the two circuits shows that the major difference is that the afterburner ignition system utilizes a full-wave rectifier rather than a half-wave as employed in the main ignition system. The pi-type RF filter in the afterburner circuit functions exactly the same as in the main ignition circuit.

From the filter circuit, the current passes through the step-up transformer (L2 and L3), which increases the voltage to a value high to ionize the airgap of the spark plug.

To insure maximum current flow, a capacitor C3 is connected in series with the secondary winding of the transformer. This establishes a series resonant circuit, since the capacitive reactance of this capacitor is equal to the inductive reactance of the secondary winding. Thus, at series resonance, circuit impedance is minimum and current flow is maximum. Capacitor C3 also limits the rate of current flow and hence the rate at which the tank capacitor C4

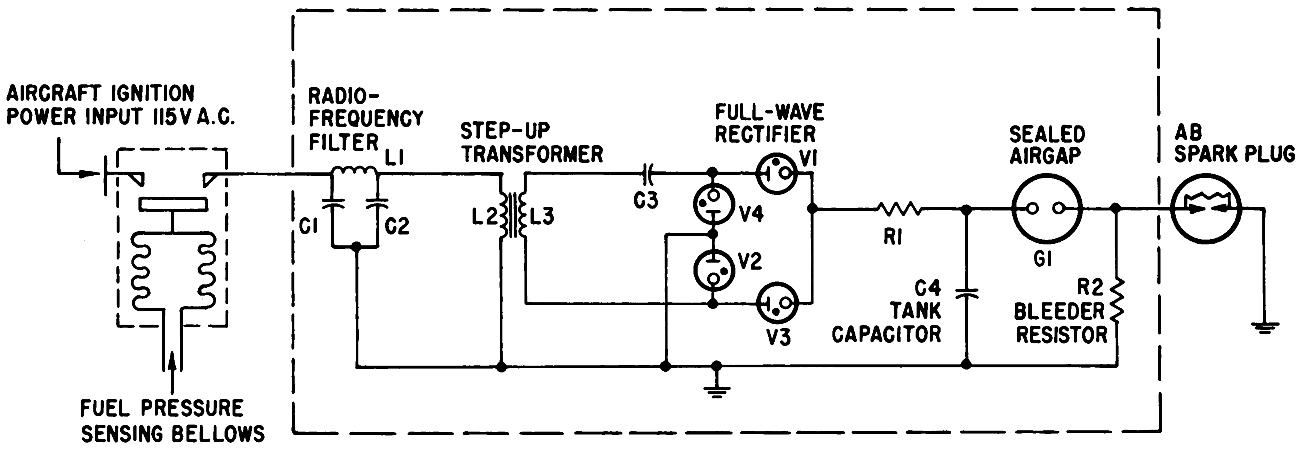


Figure 13-22.—Afterburner ignition unit schematic.

charges. This helps to control the spark rate of the ignition unit.

The voltage passes across a bridge rectifier which is formed by four diode gas rectifier tubes V1, V2, V3, and V4. The rectifying action of the bridge circuit depends upon the cathode-to-plate polarity of the diodes during each half of the input cycle. During the first half-cycle, the top of the transformer secondary winding L3 is positive and the bottom is negative. The plates of V1 and V2 are positive with respect to their cathode, so these two diodes conduct current. Current flows from L3 through V2, C4, R1, V1, and then back to L3 through C3, thus charging C4.

During the alternate half-cycle, the polarity of winding L3 is reversed. This voltage is in series with the potential developed across C3 on the first half of the cycle producing a voltage doubling action. Diodes V3 and V4 have the proper plate-to-cathode potential for conduction. Assuming L3 and C3 as the voltage source, current flow through the external circuit is from the right side of C3 through V4 to C4. Current leaving C4 flows through R1 and V3 to the lower side of L3.

As the rectified current flows to the tank capacitor C4, a charge of energy is stored in the capacitor. C4 continues to charge until the voltage across it is sufficient to ionize the sealed airgap G1. When G1 ionizes, current flows to the spark electrode. The spark electrode ionizes and provides a low-impedance path for C4 to discharge, producing a high-energy spark.

R1 is a current-limiting resistor that protects the gas diodes from damage by high-surge current during initial charging of C4. Bleeder resistor R2 stabilizes the ionization of G1, and also acts as a dummy load across the output circuit if the ignition unit is energized when the spark electrodes are disconnected. This reduces the possibility of damaging the ignition unit when servicing the ignition system.

ELECTRODES.—The igniter plug (electrode) is used to provide the spark which is necessary to start the engine. The plug is of the surface-gap type, which is self-ionizing and used in low-tension applications.

The plug consists of an inner and outer electrode with insulation between them. When the voltage between the electrodes is sufficiently high, the airgap will ionize and allow the tank capacitor to discharge across the electrodes. The discharge of the tank capacitor produces the high-energy sparks needed to start the engine. A typical igniter plug is shown in figure 13-18.

IGNITION SYSTEM TESTING AND MAINTENANCE

RECIPROCATING ENGINES

Ignition difficulties in reciprocating engines will normally be confined to such engine malfunctioning as high rpm drop, rough operation, low power output, backfiring, overheating, and failure to start. When faulty ignition is indicated, determine what component of the ignition system is causing the difficulty and then readjust, repair, or replace it.

When checking the ignition system, operate the engine at cruising manifold pressure. Operate an engine on one magneto at a time and observe the tachometer (rpm indicator) for a drop in rpm. Turn the ignition switch back to BOTH and allow the engine to operate normally and then switch to the other magneto. If the drop in rpm is too great, locate and correct the trouble.

When checking the magneto, make certain that it is securely mounted and properly safetied and that all electrical connections are tight. Check the condition of the breaker points. Clean the breaker compartment with a cloth moistened with a recommended cleaning solvent. Oil on the breaker points will result in serious burning of the contact surfaces. If the points are burned or excessively pitted, replace the entire magneto. When checking the condition of the breaker points, do not separate the points to the extent that the spring may be weakened and result in faulty operation. Check the timing of breaker point opening in accordance with instructions in the manuals. Inspect the cam for proper lubrication. If lubrication is required, refer to the pertinent manual for the correct procedure. Remember that most magnetos require no lubrication between overhauls.

When inspecting the distributor, check the distributor block and rotor for cracks and evidence of arcing; check the rotor for security of mounting; clean the distributor with a cloth moistened with an approved cleaning solvent.

Check the ignition switch for security of mounting and condition of electrical connections. With the engine running at low speed, turn the ignition switch momentarily to the OFF position. If the engine does not cease firing, the switch or connection is probably defective. Stop the engine, but do not rotate the propeller until you find and correct the trouble.

When inspecting the starting vibrator or booster coil, check the security of the mounting and the tightness of all electrical connections. If the unit fails to operate, check the external wiring. If the booster coil or starting vibrator is defective, replace the unit. Make no adjustments in the field.

One of the most troublesome units of the aircraft electrical system is the ignition harness. Failure of the harness is generally caused by moisture and oil collecting inside the metal housing. This weakens the insulation and affords opportunity for leakage of the high voltage to the case. All mechanical connections should be inspected frequently to insure tightness. Tight connections decrease the amount of oil and water that can seep into the harness shielding.

The common method of testing a harness is to apply a high voltage between the ignition wire and the shield. A suitable indicating instrument, such as a neon tube, is placed in the circuit. The distributor blocks are removed before testing in order to prevent application of high voltage to the magneto elements. The flexible leads to the spark plugs are removed in order to prevent high voltage from jumping the spark gap, which would give a false indication. If the spark plug wires are left connected, any small charge of gas mixture in the cylinders will be ignited. This might result in injury to anyone near the propellers.

The high-tension shield tester, shown in figure 13-23, is designed to operate on 110 volts a.c. Its output is about 10,000 volts because of the action of the step-up transformer. The high voltage is sufficient to break down any part of the circuit that is defective.

A neon bulb is connected in the output circuit of the transformer. If a short exists in the ignition circuit, it completes the circuit to the opposite side of the transformer. Therefore, the neon bulb will glow. If the insulation is satisfactory, the return circuit to the transformer will not be complete and the neon bulb remains dark.

There are three leads attached to the instrument. To insure the safety of the operator, it is important that the leads be connected in the proper order. Each lead is marked to indicate its purpose. The first lead to be connected is the earth ground lead; this must be secured to a good ground such as a metal beam or a tiedown cleat. The second lead is connected to the engine ground. The best contact in this case is the ignition shield. The third lead is clipped to the particular wire which is to be tested. After the three leads have been properly connected, the tester is plugged into the 110-volt power source. Thereafter, the third lead may be attached in turn to each of the cables undergoing test.

The testing instrument is equipped with a voltmeter and a variable resistor. The resistor insures operation of the device at the correct input voltage. The ratio of the step-up transformer is rather high so a few volts change in the primary voltmeter will change the output voltage greatly. The change may be sufficient to break down a good harness.

When using this tester, flash readings should be taken. The tester should not be kept on for

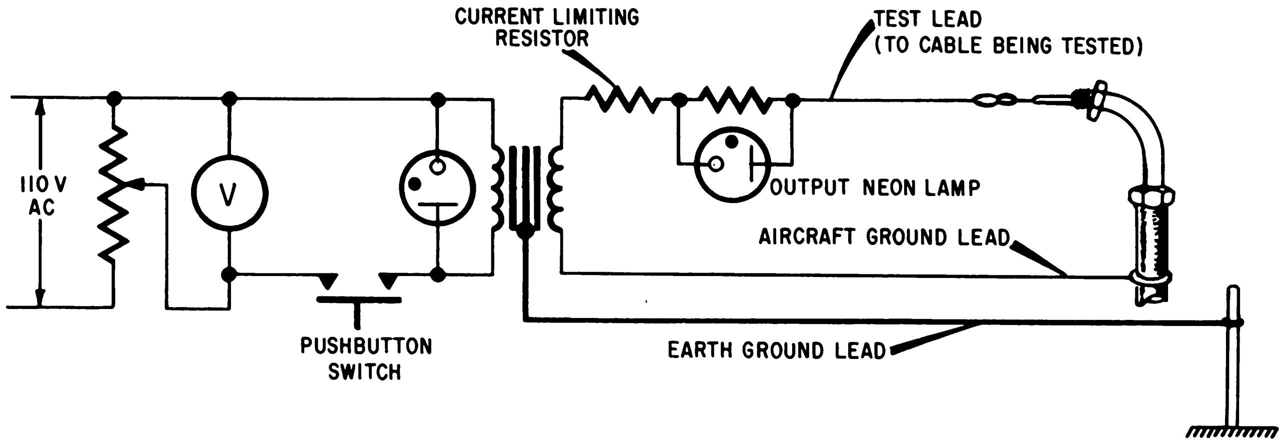


Figure 13-23.—High-tension shield tester.

any great length of time. Frequently, an ignition system will withstand flash readings but will break down completely if subjected to the tester for more than a few seconds. This is particularly true when there is moisture in the system. The continued application of a high voltage across a system that has broken down forms a carbonized track. Consequently, what might have been a minor breakdown becomes a major one.

High-Voltage Insulation Tester

Another type of high-voltage insulation tester commonly in use is shown in figure 13-24. All high-voltage testers are similar in many respects. They are designed for the purpose of detecting or measuring leakage paths through or across high-voltage insulation. Spark plug cables, distributors, and various other parts of ignition systems can be tested for adequate insulation resistance at the operating voltages. Many different pieces of insulation other than ignition equipment can also be tested at high voltage.

The unit shown in fig. 13-24 is portable and connecting cables and test leads are stowed in the cover. It measures the insulation resistance in megohms at any d-c voltage between 2,000 and 15,000 volts. The voltage applied to the insulation drops more or less in proportion to the leakage current, thereby preventing destructive damage to the part being tested.

The equipment consists of a voltage doubler rectifier circuit with indicating meters and control circuits. The input primary supply voltage may be either 117-volt, 60-cycle a.c., single-phase, or 24-volt d.c. (battery source) at 3.3 amperes. When a 24-volt battery source is used, this d-c supply is converted to 117 volts a.c. by a vibrator type inverter contained in the unit.

The unit's high-voltage transformer is energized by alternating current supplied through a continuously variable autotransformer (commonly called a VARIAC). The secondary of the high-voltage transformer produces a-c voltages from 0 to 10,000 volts rms, depending upon the setting of the VARIAC. High-voltage direct current is produced by means of two high-voltage capacitors and two half-wave rectifiers connected in a voltage doubler circuit. Direct-current voltages from 0 to 15,000 are available. The two half-wave rectifiers are of the cold cathode type and require no filament power or any warmup time.

The output of the voltage doubler circuit is connected to an adjustable ball type spark gap through a 7,500-ohm, 25-watt wire-wound resistor. One side of the spark gap is grounded to the equipment panel.

The voltage at which the spark gap breaks down (sparks) can be adjusted very closely to the desired maximum voltage to be applied to the equipment being tested. In the event of an input supply voltage surge or should the operator turn the VARIAC too high, a spark jumps across the safety gap, short-circuiting the output test lead circuit. This prevents applying excessive voltage to the equipment being tested. The gap can be set by a screw adjustment on the front panel to break down at any voltage desired.

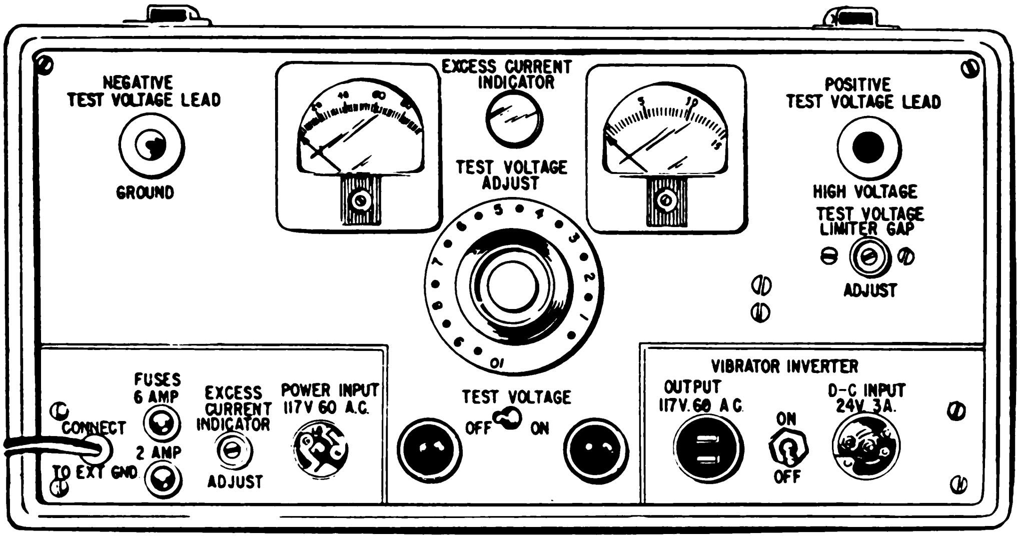


Figure 13-24.—High-voltage insulation tester.

When the output voltage exceeds the breakdown voltage of the safety gap by a slight amount, short bursts of sparks jump across the gap. If the voltmeter, located on the front panel, is read just before the spark occurs, this reading indicates the maximum voltage that can be applied across the equipment being tested. For example, if you want to apply 10,000 volts to the part being tested, the spark gap should be set to arc at about 11,000 volts. A neon indicating lamp, located on the front panel, lights up every time the spark gap breaks down. The operator is protected from shock after turning off the equipment by means of a high-voltage capacitor discharge switch that is mechanically linked to the TEST VOLTAGE switch.

For detailed information concerning the description, operation, and maintenance of a tester, consult the instruction manual that has been published for that particular piece of equipment.

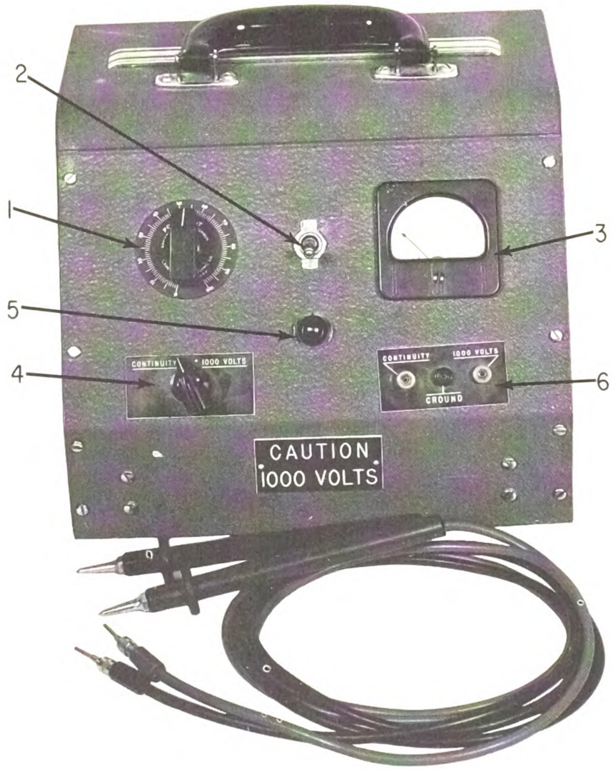
Low-Tension Ignition Harness Tester

The Low-Tension Ignition Harness Tester is a portable electrical instrument designed specifically to perform continuity and leakage tests upon low tension or primary wiring circuits of ignition systems. Incorporated within the cabinet are a 2.5 volt a-c continuity test circuit and a 1,000 volt d-c leakage test circuit. The tester is designed to operate from a 115-130 volt, 50/60 cycle, a-c power source.

The following controls and parts are located on the panel of the instrument, as shown in figure 13-25.

1. The high voltage control knob.
2. The main ON-OFF switch which controls the 115 volt input to all circuits.
3. The milliameter which indicates the merit of the insulation being tested when making 1,000 volt d-c leakage tests.
4. The selector switch, which has two positions—CONTINUITY and 1,000 VOLTS. This switch controls the selection of the desired test circuit for the particular operation being conducted.
5. The pilot or signal lamp which indicates continuity when conducting continuity tests, and indicates that primary power is applied when the selector switch is in the 1,000 VOLTS position.
6. The test lead jacks which are provided for the connection of the insulated test leads supplied with the tester.

A simplified schematic diagram of the 1,000 volt d-c test circuit is depicted in figure 13-26. The 115 volt a-c input is fed into the primary of the power transformer through the autotransformer. The high voltage secondary of the power transformer is connected to the storage capacitor through the rectifier tube. Rectified



1. High voltage control knob.
2. ON-OFF switch
3. Milliammeter.
4. Selector switch.
5. Pilot lamp.
6. Test lead jacks.

Figure 13-25.—Low-Tension Ignition Harness Tester.

pulses of direct current passing through the tube are stored in the form of a charge on this capacitor. The rectifier tube filament current is supplied from a separate filament transformer. The pilot lamp indicates when power is applied to this circuit.

Connected across the storage capacitor are the output terminals and the milliammeter. The meter circuit consists of a 0-1 milliampere meter in series with a 1 megohm resistor. The current to the meter and the output terminals is limited by 250,000 ohms of resistance (two 500,000 ohm resistors connected in parallel).

When the voltage control knob is adjusted so that the meter reads full scale, the voltage across the meter-resistor combination and the test leads is:

$$E_t = IR = 0.001 \times 1{,}000{,}000 = 1{,}000 \text{ volts.}$$

The voltage across the 250,000 ohm resistance is:

$$E_r = IR = 0.001 \times 250{,}000 = 250 \text{ volts.}$$

The voltage across the capacitor is:

$$E_c = E_t + E_r = 1{,}250 \text{ volts.}$$

When the tester is connected across leaky or defective insulation, current will pass through the defect. This causes an increased voltage drop in the 250,000 ohm resistance, thus reducing the voltage on the test lead terminals and across the meter circuit. This causes the meter reading to decrease. The meter reading may therefore be taken as an indication of the merit of the insulation. If the meter reads less than 0.8 milliampere the insulation is unsafe and should be investigated. (The 0.8 milliampere

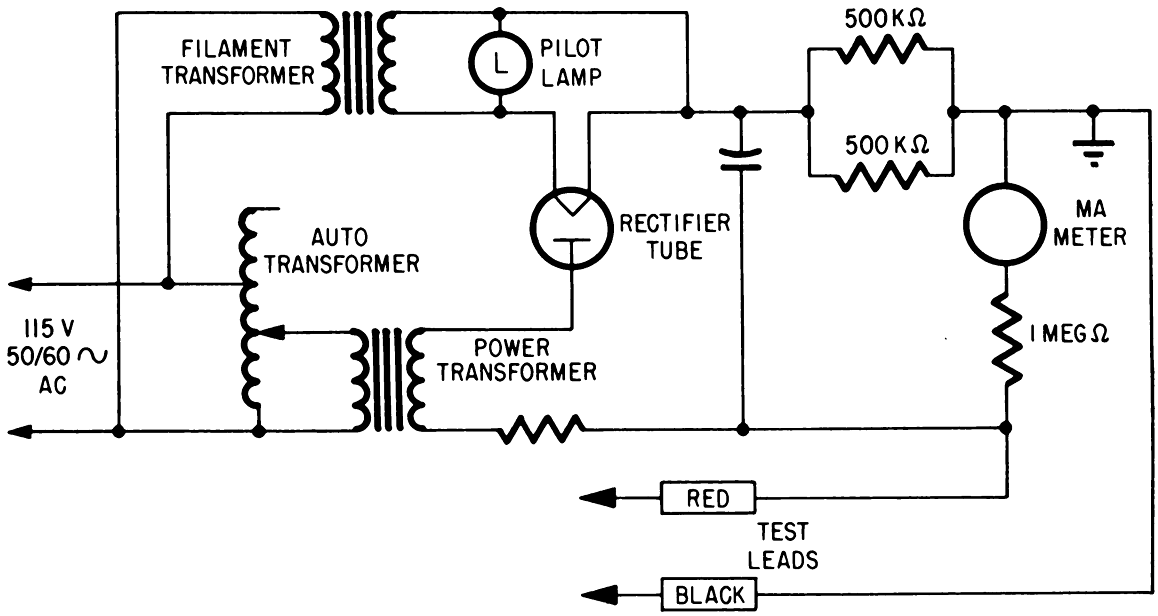


Figure 13-26.—Simplified schematic diagram of the 1,000-volt d-c test circuit.

reading corresponds to an insulation resistance of approximately 1 megohm for the wire insulation being tested.). Figure 13-27 is a graph showing the approximate values of insulation resistance which correspond to various meter readings.

Before connecting this tester to the ignition harness, the AE should consult the applicable manual for the correct operating and testing procedures. NOTE: When using either high- or low-tension ignition harness testers, adhere strictly to all safety precautions. These units are capable of delivering severe shock.

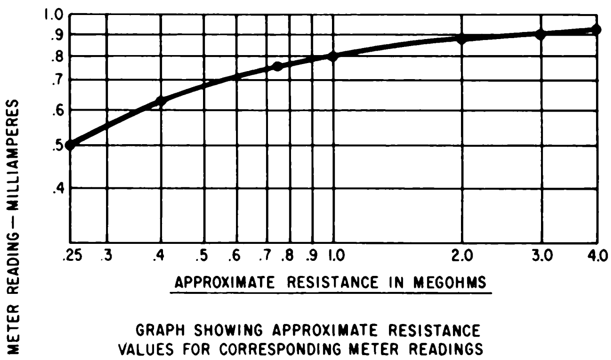


Figure 13-27.—Meter conversion chart.

JET IGNITION SYSTEM TESTER

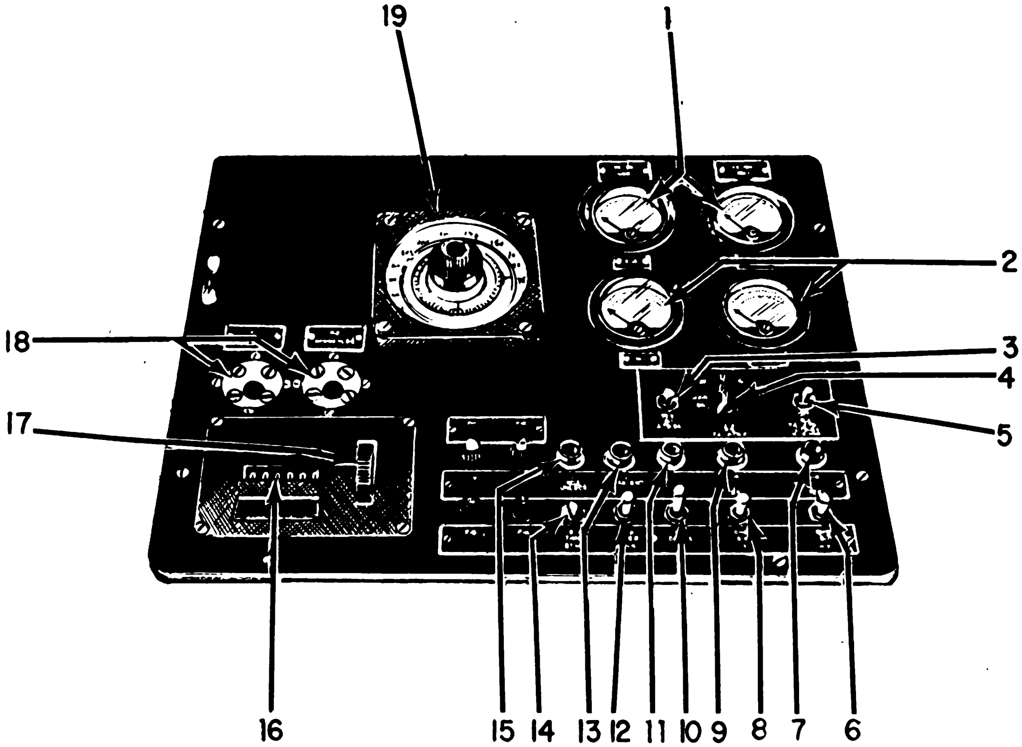
This ignition tester is used to detect and isolate faults in the jet engine ignition system. The tester can be used in making the following checks:

1. Operational check of the ignition system from the engine through the ignition unit to the spark plug.
2. Operational check of the spark plugs.
3. Check of the ignition unit output in sparks per second.
4. Power input to the ignition unit.

The panel of the ignition system tester is shown in figure 13-28.

The wiring diagram of the tester, is shown as it is connected to an engine in figure 13-29.

The procedures for the use of the tester can be found in the Operation and Service Instruction Manual, as well as in the Maintenance Instructions Manual for the engine ignition system to be maintained.



1. A-c and d-c voltmeters (M3 and M4).
2. A-c and d-c ammeters (M1 and M2).
3. Main ignition primary—secondary selector switch (S1).
4. Main ignition energy level switch (S2).
5. A/B ignition test on-off switch (S3).
6. High-voltage spark plug test switch (S7).
7. High-voltage spark plug test light (I5).
8. Low-voltage spark plug test switch (S6).
9. Low-voltage spark plug test light (I4).
10. Spark rate counter power on-off switch (S8).
11. Spark rate counter power indicator light (I3).
12. Spark rate counter timer power on-off switch (S9).
13. A/B ignition switch test light (I2).
14. Spark rate counter timer start switch (S10).
15. Nozzle unlock switch test light (I1).
16. Spark rate counter.
17. Spark rate counter reset knob.
18. Hi-voltage (P1) and low-voltage (P2) slave spark plugs.
19. Spark rate counter timer.

Figure 13-28.—Jet Ignition System Test Panel.

SPARK PLUG CARE

The spark plug is the unit of the ignition system that requires more attention than any other; the precision with which it is built requires that it be handled as a delicate instrument. This point should be emphasized to those who have never worked with spark plugs. Spark plugs should never be thrown around, but should be placed carefully in special racks drilled to

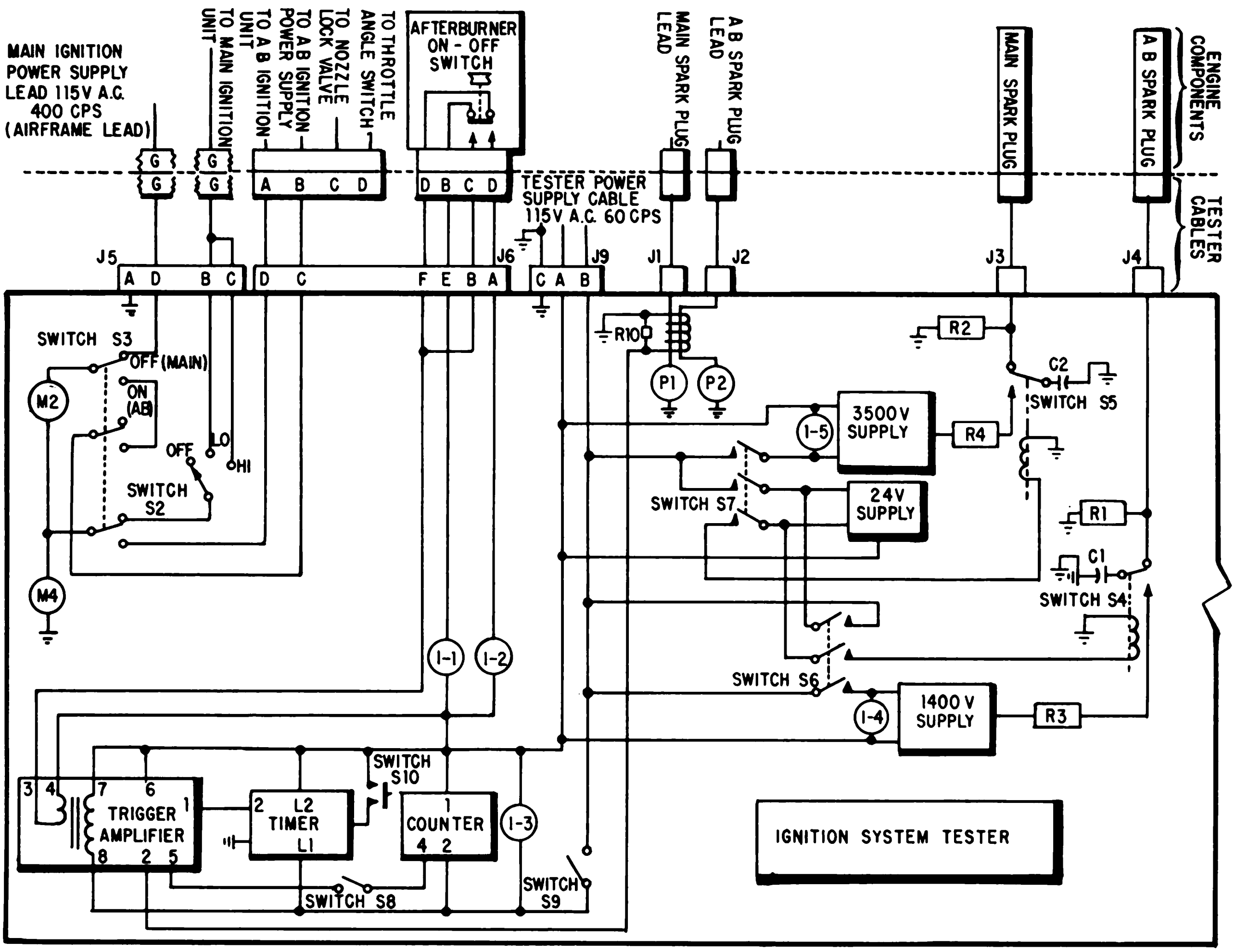


Figure 13-29.—Wiring diagram of the jet ignition system tester.

receive the plugs, once they are removed from their cartons.

Installation and Removal of Plugs

Removing and installing plugs is almost impossible without the proper tools. Never try to remove or replace a spark plug without the proper tools. This could result in unseen damage to a plug and cause engine failure.

The wrench hex size must fit the spark plug hex. If the wrench is too big, it will slip and probably round the hex corners on the plug. There are two standard sizes of spark plugs. These are 7/8-inch hex and 13/16-inch hex. Under no circumstances should chisels, punches, pipe wrenches, or pliers be used for removing or inserting a plug.

Always take care in removing or inserting a plug to prevent the wrench from tilting to one side or slipping and striking the head of another plug. Also, be careful not to damage the shield around the cable from the plug to the distributor. Dents in this cable will cause arcing through the insulation in the cable and insufficient spark at the electrode gap. Use only torque-indicating socket wrenches of the correct size to insert spark plugs.

When removing a spark plug, often more pressure must be used than was required to insert the plug. The main reason for this is that the lower threads have become filled with

carbon that forms inside the cylinder head. Normally, additional torque will not damage a plug; however, removed plugs should be tested before being replaced. Never use the torque handle in removing plugs.

Spark plugs should be removed in pairs from each cylinder and placed in the holder by cylinder number. The conditions of the plugs indicate the operation of the cylinder. Always check to see that the sparkplug gasket has come out on the shell threads. When the plug is out, be careful that no dirt or chips of carbon or other foreign matter falls into the open cyclinder.

Inspect the removed plugs for unusual conditions. Signs of a battered spark plug nose and bent electrodes indicate that some foreign material has entered the cylinder.

Plugs that are seized or "frozen" can sometimes be loosened by first putting pressure on the wrench in the tightening direction before backing the plug out. If this does not work, it is usually possible to remove a plug with the aid of a CO_2 bottle. The CO_2 coming from the container is very cold and causes the plug to contract; consequently the plug can be unscrewed with little difficulty.

Often a tight spark plug can be removed by applying penetrating oil to be outside of the plug directly and to the inside of the plug through the other spark plug hole in the cylinder. After about 15 minutes the plug can be started by using a vibrating hammer similar to an electric riveting gun to apply vibrations down on the top of the plug socket wrench. If a riveting gun is not available, tap on the top of the wrench with a small hammer to produce the same result. Once it has loosened, screw it in and out a few threads at a time until it seizes or "freezes" again. Repeat the procedure until the plug can be removed. A plug that is removed in this manner must be scrapped.

If the spark plug shell breaks rather easily when removing the plug, the shell has probably been cracked during its last or some previous installation by excessive torque. When a plug cracks, it can sometimes be removed by inserting a large screwdriver down between the ground electrodes.

If the broken part of the shell cannot be removed without damage to the bushing threads or without getting metal chips into the cylinder, it is necessary to change the cylinder. However, in an emergency, it is permissible to saw through the sides of the plug in several places and collapse the plug so that it can be removed. Before doing this, however, check the procedure with current regulations.

Preinstallation Inspection of Plugs

Although the spark plugs that are drawn from supply have been rigidly inspected, they must still be inspected before inserting in an engine. The main things to check for are as follows:

1. If the package from which the cartons were removed indicates abuse, reject all spark plugs in the package and return them to the supply system; draw a new set of plugs.
2. Carton lint or foreign matter in any of the gaps or in the firing chamber. Remove with airblast.
3. Evidence of rust preventive compound between electrodes in firing chamber and on core insulator. Remove by dipping firing end only in proper solvent and dry with airblast. NOTE: Do not use carbon tetrachloride.
4. Presence of badly damaged threads and electrodes. Exchange for new spark plug.
5. Presence of foreign matter in shielding barrel, which may prevent cable connector from making good contact with core contact button. Remove with airblast.
6. Crack or damage in the center electrode insulator or shielding barrel insulator.
7. Presence of steel fibers in terminal well, resulting from cleaning terminal threads with wire brush. Remove with airblast or by other nonmetallic means.
8. Cracks or evidence of fracture at foot of the last top thread immediately below the shell flange or seat. Due to a previous excessive installation torque, a small crack or break may develop at that point; therefore, it is of utmost importance that a rigid visual inspection be given the shell threads. Exchange for new spark plugs.
9. Visible cracks in lower end of ceramic core insulation. Exchange for new spark plugs. NOTE: Use 2- or 3-power magnifying glass in making visual inspection of spark plugs.
10. Incorrect gap setting. Check with gap gage.
11. Remedy any evidence of thread discrepancy by running the threads through the proper size die, or if damage is extensive, replace spark plug with one that is satisfactory. Do not use spark plugs with flat or eccentric threads. Minor imperfections of threads should

be corrected where possible by using a small three-cornered file. When a dye is used, it should be hand operated.

12. Unsatisfactory condition of a gasket. Do not use a gasket which has been excessively flattened, scored, or dented by previous use.

13. Exchange spark plugs that have the nose of the insulator cracked, a cracked ceramic insulator, case hex damage, barrel distortion that might fracture the insulator, or cracked threads.

Causes of Bad Plugs

Spark plug fouling is an everpresent problem and will increase in importance as engine power and allowable manifold pressures increase. Plugs can be fouled during flight by diving or gliding for long periods of time at excessively low manifold pressures. Oil pumped past the piston rings during this time may not burn off the plugs while the engine is cool, and will foul the spark plugs with carbon and oil.

Spark plugs may be fouled during ground running by oil or by carbon resulting from incomplete combustion of the gasoline. This type of fouling is the cause of many engine failures at takeoff. The majority of cases of carbon fouling are caused from improperly set idle mixture. When the insulator of the spark plug first becomes covered with oil and sootlike deposit of carbon, the plug will still spark normally at the gap at low, medium, and sometimes high manifold pressures, depending on the degree of fouling. At high manifold pressures it is easier for part of the spark to go through this carbon and oil than across the electrodes. This carbonizes the oil between the particules of carbon and eventually a continuous carbon track is formed across the insulator and no spark occurs at the gap. The result during takeoff is almost normal power at the beginning of the takeoff run, followed by sputtering and misfiring which is often diagnosed incorrectly as detonation.

Operation of a cylinder with only one plug firing for any length of time will foul the nonfiring plug. The deposited material on the inoperative plug may cause preignition. Mechanical failure of a plug may also cause preignition. For instance, if the center electrode is broken or cracked, it cannot conduct heat from the end of the electrode as it should. This can cause the end of the electrode to become hot enough to cause preignition and serious damage to the valves, piston, and cylinder. The center electrode can be broken by rough handling, such as dropping, piling plugs together, or tightening past torque wrench limits.

Loose center electrodes in spark plugs can result from improper assembly or exceeding the torque wrench limits. This may pull the lower part of the outer steel shell away from the ceramic material, thus breaking the seal. Some ceramic plugs are very susceptible to loosening of the center electrodes.

Most troubles attributed to spark plugs are actually caused by failure of other parts of the electrical system, such as the magneto, shielding, wiring harness, and so forth. The ignition system may be in poor condition, but will still fire new spark plugs. After several hours of operation, the gap will erode and the ignition system will not fire the plugs. Spark plug malfunctioning should always be looked upon with suspicion, and a very thorough check of the rest of the ignition system should be made before attributing the trouble to faulty spark plugs.

Proper installation of spark plug terminal sleeves is essential to good ignition system performance. Many reports of breakdown of spark plug leads and terminals have been traced to ground operation with the cowl flaps closed, ground operation with the engine cowling removed, pilots taxing with cowl flags closed, or closing cowl flaps immediately after stopping the engine.

CLEANING JET IGNITER PLUGS

Spark igniters should be degreased and the outer shell cleaned with a wire brush. If deposits exist on the ceramic tip, and center and ground electrodes, they should be removed by light abrasive blasting. However, this abrasive blast should not be used on the ceramic barrel surface. The ceramic barrel of the igniter should be cleaned with a soft swab and a suitable solvent, such as P-S-661B. Dry and clean the igniter by means of an airblast on the ceramic surface at the firing end, through ventholes, and into the igniter well.

NOTE: Do not use an abrasive blast in this area, since this will remove the glaze on the ceramic surface.

The barrel and shell threads should be visually inspected, and if necessary chase the barrel and shell threads with a die. Visually

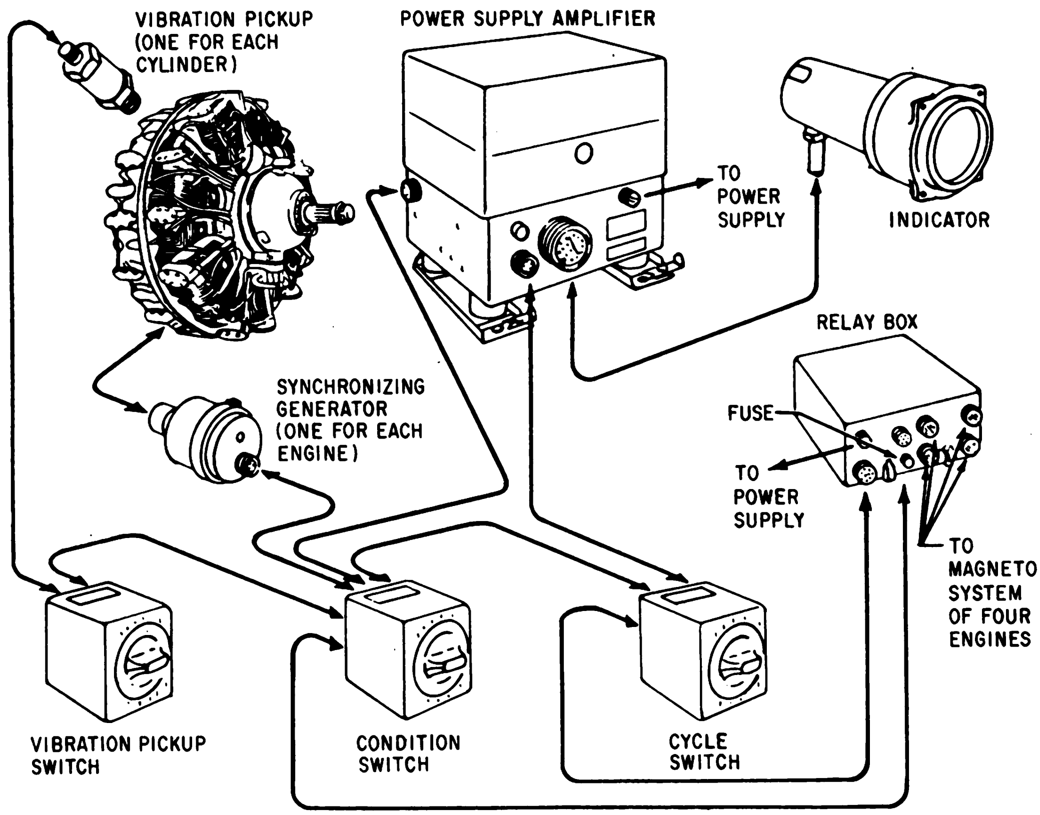


Figure 13-30.—Basic diagram of an airborne engine analyzer.

inspect the exposed ceramic section. Any cracks are cause for rejection. The center electrode, if the erosion is within that specified in Service Instruction Manual, may be continued in service. The igniter should be fired on a bench system, and the manner of firing should be observed and recorded. If the firing is normal, the igniter should be made available for future installation. The firing check can be performed by operating the spark igniter with the normal engine ignition system as a source of current and visually comparing the spark produced with that produced by a new spark igniter.

NOTE: Before touching the spark igniter after performing the firing check, allow sufficient time to elapse for complete dissipation of energy from the ignition system.

ENGINE ANALYZERS

Engine analyzers are used to detect, locate, and identify ignition and vibration abnormalities in reciprocating engines. Figure 13-30 shows a typical diagram of an airborne engine analyzer. This is accomplished by projecting on a cathode ray tube the voltage across the magneto primary circuit or the voltage induced into a coil by cylinder wall vibration. By comparing the patterns obtained from a faulty engine and those taken during normal operation, the trouble may be located and corrective measures may be taken. It is not within the scope of this training course to cover the details of use and complete operation of engine analyzers.

CHAPTER 14

CIRCUIT MAINTENANCE AND TROUBLESHOOTING

D-C POWER BUSES

Although a knowledge of the basic electrical power systems in aircraft is necessary for pilots and other aircrewmen, it is the primary responsibility of the Aviation Electrician. His duties require a detailed knowledge of the operation and maintenance of these systems.

The electrical power system of current aircraft requires that distribution to the various electrical components be controlled automatically. The system, designed to keep the pilot and flight engineer informed as to the condition of the generator system and to provide for automatic removal of the nonessential electrical loads, assures added safety of flight through conservation of emergency power.

The most important function of a bus system is to provide a low-resistance path for heavy currents and thus maintain uniform voltage to all of the aircraft's electrical loads. The bus system provided for a particular aircraft depends on the mission as well as the design of that aircraft.

The basic buses used in various aircraft are the primary, secondary, monitor, essential, and battery buses. An ''essential'' bus is provided in newer naval aircraft. To this bus are connected all loads that are essential for flight under conditions demanding maximum use of electrical equipment; for instance, during night flying on instruments with icing.

Figure 14-1 illustrates a twin-generator, 4-bus, d-c power system. The primary bus (A) receives power from the battery through the electrical power switch (B) when the switch is in the BAT & GEN or BAT ONLY position. Essential loads are connected to the primary bus; nonessential loads are connected to the secondary and monitor buses. The primary bus is connected to the secondary and monitor buses through contacts of the secondary bus relay and the monitored bus relay, respectively. These relays are energized through contacts of the bus control relays. Each bus control relay coil is energized from the IND terminal of its respective generator control relay (reverse current relay).

In the event of double generator failure, the bus control relays are deenergized and the secondary and monitor buses are disconnected from the primary bus. The secondary bus may be reenergized by the secondary bus relay transfer switch, which is actuated when the landing gear control lever is in the WHEELS DOWN position. The secondary bus can also be recovered by placing the battery-generator switch in the BAT ONLY position. This provides a means whereby, during an emergency, electrical power is supplied to equipment on the secondary bus whose operation is essential to the safe landing of the aircraft.

Aircraft with fixed landing gear, such as helicopters, are not equipped with a bus relay transfer switch, but in many cases are equipped with an override switch which performs the same function.

PRIMARY BUS

Only those loads which are essential for flight control of the aircraft in the event of generator system failure, such as instruments, instrument lights, and cockpit lights, are connected to the primary bus.

While the primary bus supplies d-c power directly to some equipment, it serves as a distribution point through which d-c power flows to the secondary and monitor buses. This flow is dependent upon the power source, actuation of relays, and position of the battery-generator switch. When the battery-generator switch is placed in the BAT & GEN or BAT ONLY positions, battery power is supplied to the primary bus. D-c generator power is supplied to the

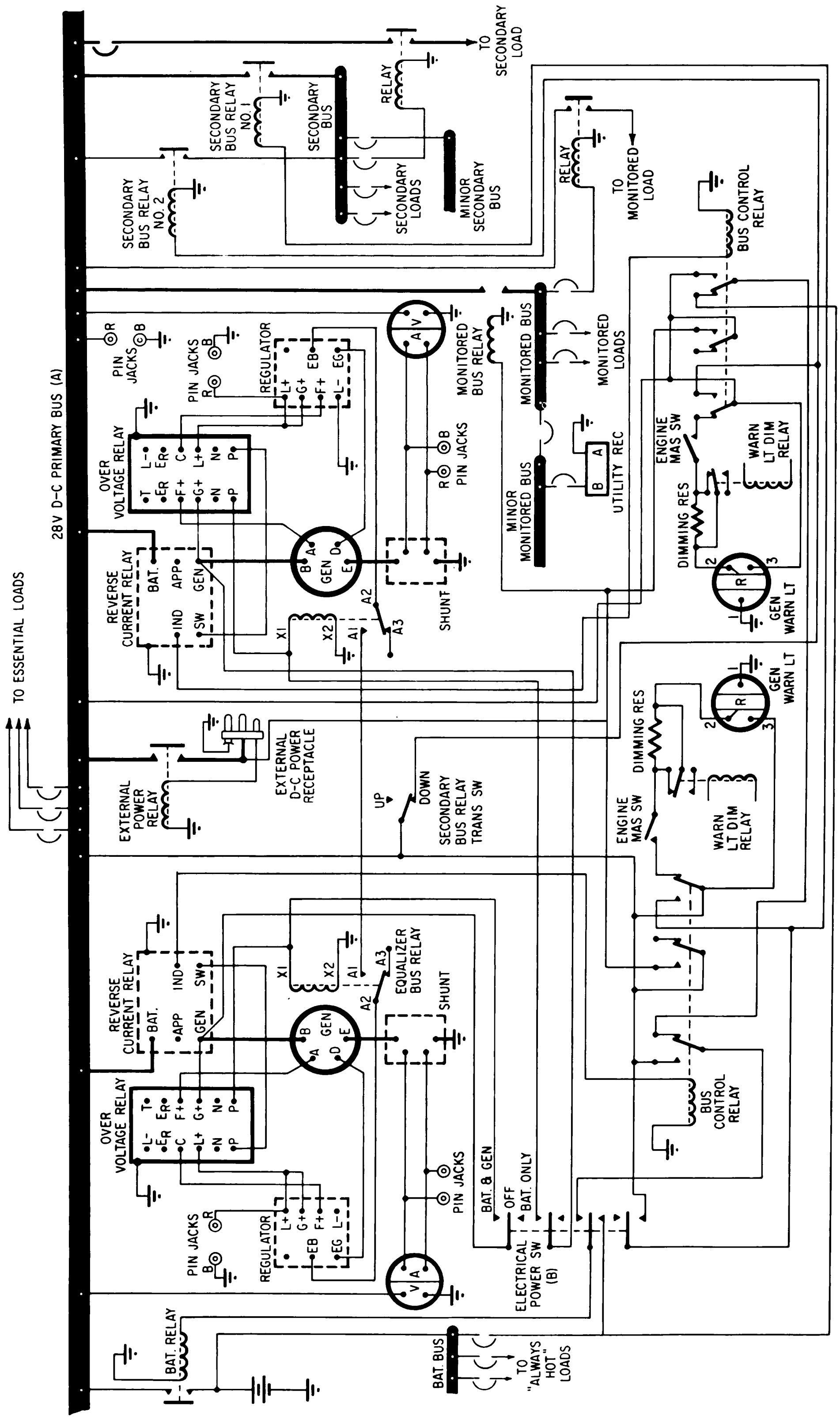


Figure 14-1.—A twin-generator, d-c power system.

primary bus when the d-c generators are in operation and the battery-generator switch is placed in the BAT & GEN position. External power is supplied to the primary bus regardless of the position of the battery-generator switch.

SECONDARY BUS

Those loads which are of secondary importance to flight or combat effectiveness, such as radar, pitot tube heater, and exterior lights, are connected to the secondary bus.

In normal flight operation with the battery-generator switch on the BAT & GEN position, d-c generator power actuates the bus control and secondary bus relays to allow current to flow from the primary bus to the secondary bus. When the battery-generator switch is on BAT ONLY, battery power actuates secondary bus relay No. 1 to make this connection, and thus energizes the secondary bus. Also, lowering the landing gear will energize the secondary bus with the battery-generator switch on either BAT & GEN or on BAT ONLY position. D-c power from an external power source will energize the secondary bus only if the battery-generator switch is on BAT ONLY or if the landing gear control lever is in the WHEELS DOWN position.

MONITOR BUS

Those loads which can be dispensed with in the event of generator system failure, such as utility receptacle and gun camera, are connected to the monitor bus.

The monitor bus can be energized only from the d-c generators or from an external d-c power source. With the battery-generator switch in the BAT & GEN position, and with either d-c generator operating, power is supplied from the d-c primary bus to the monitor bus relay. This allows power to be delivered from the primary bus to the monitor bus. External power is supplied from the primary bus through the monitor bus relay to the monitor bus.

ESSENTIAL BUS

The installation of the essential bus systems provides maximum reliability and least vulnerability to electrical or mechanical damage.

This bus provides power for such loads as electric flight instruments, flight stabilization equipment, other electric devices essential to flight control, warning systems, emergency interior lighting and communication, and navigation and identification equipment. The essential bus is supplied power from the emergency power source. In older aircraft the essential bus is often referred to as the emergency bus.

BATTERY BUS

Only specifically authorized loads are connected to the battery bus, such as emergency bomb release, boarding lights, and ground-operated canopy control.

With the batteries installed, the battery bus remains energized regardless of the position of the battery-generator switch.

MINOR BUS

The buses just described are sometimes broadly classified as major buses. Each major bus may be subdivided into minor buses in order to facilitate power distribution on some aircraft. For example, minor buses, such as the d-c instruments bus and the console lights bus, are sometimes located in the cockpit so that a source of power may be established in close proximity to the equipment. Some aircraft are equipped with additional special-purpose buses, such as radio buses and armament buses. The minor buses differ from the major buses in that they supply equipment with fused or protected power from one of the major buses. Figure 14-1 includes a number of minor type buses.

A-C SYSTEMS

The primary electrical system in current naval aircraft is alternating current. The AE may encounter variations among different types of power bus arrangements. However, the principal difference that will be noted is the difference between a-c buses and d-c buses.

D-c buses are usually designed for parallel operation if the aircraft has more than one d-c generator. The generators are all tied into the main power bus and all supply primary power concurrently.

A-c generators for aircraft usually operate independently; that is, their outputs are not paralleled into the primary power bus. Each

generator has its own primary bus, and supplies certain other selected buses without interconnection to the primary buses of the other generators. However, provisions are made for automatic or manual/automatic switching in case of emergency. Thus, any generator can be switched into any bus when necessary.

Provisions are also made in a-c systems for a lower voltage, usually 26 volts, which provides power for those instrument and control systems which operate on this lower voltage. This 26-volt bus is supplied by a stepdown transformer arrangement which is in turn supplied from the main or primary a-c bus system. On aircraft that have no battery or d-c generators, the a.c. is rectified to furnish d-c power for all d-c loads.

CIRCUIT TROUBLESHOOTING

Troubleshooting consists of locating the fault and correcting it. Repairing the trouble usually involves the replacement of defective parts, but locating trouble is often a more tedious job, which requires a knowledge of the equipment and mechanical proficiency. Efficient troubleshooting requires an orderly and systematic procedure.

TYPES OF TROUBLE

If an electrical device becomes inoperative, either the device or its circuit is at fault. Circuit troubles may be classified as open circuits, short circuits, and low voltage circuits.

Open circuits are those in which the flow of current is interrupted by a broken wire, defective switch, or any other discontinuity in the current path. Checking for opens (seeing if the circuit is complete or continuous) is called continuity testing.

In short circuits, current flows, but in paths not intended. Short circuits may be classified as grounded or nongrounded.

Grounded circuits are caused by some conducting part of the circuit making contact either directly or indirectly with the metallic framework of the aircraft. Grounds have many causes, the most common of which is the fraying of insulation from a wire, allowing the bare wire to come in contact with the metal ground.

Grounds are usually indicated by blown fuses or tripped circuit breakers. These, however, may also result from a short other than ground. A high-resistance ground may also occur where not enough current can flow to blow a fuse or open a circuit breaker.

A nongrounded short circuit is one where two conductors accidentally touch directly or through another conducting element. A screw lodged between two insulated terminals in a junction box, for example, would constitute a short circuit. In a short circuit of this type, enough current may flow to blow a fuse or open a circuit breaker. Short circuits of this type do not commonly occur.

Low voltage circuits are those in which the voltage is abnormally low due to a loose or dirty contact or connection somewhere in the circuit. Low voltage is indicated by dim lights, slow running motors, and chattering relays.

TEST EQUIPMENT AND METHODS

Testing can be carried out with either live circuits or dead circuits. Circuit defects can sometimes be more readily located by one method than another, depending upon the type of circuit and trouble. When testing with live circuits, make certain all power is removed while the circuits are being worked on.

The surest way of removing all power from the circuits to be worked on is to disconnect the battery by removing the quick-disconnect plug to the battery and removing all external power supplies. The battery master switch deenergizes most circuits, but the "always hot" circuits are not affected. Such circuits include the battery switch, boarding or anchor lights, bailout bell, and other emergency circuits—in fact, any circuit connected directly to the battery or battery bus.

Take every precaution to insure that the electrical circuits are dead before they are handled.

When testing dead circuits, remove all external power and disconnect the aircraft's battery from the electrical system by means of the battery master switch. If the aircraft is not equipped with a master switch, or if the circuits under test do not pass through the master switch, remove the quick-disconnect plug in the battery circuit.

Continuity Checkers

A continuity checker is needed for testing dead circuits. This unit utilizes a power source

(usually a small dry cell battery) in conjunction with an indicating device, such as a voltmeter, lamp, buzzer, or headphones. Headphones indicate a steady current flow by giving a "click" when the circuit is made and when it is broken. A suitable continuity tester can readily be made from a flashlight in an emergency.

FLASHLIGHT TESTER.—A flashlight modified for use as a continuity checker is shown in figure 14-2. This modification does not

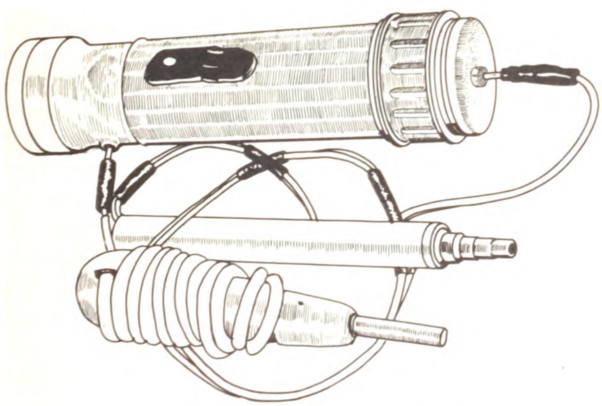


Figure 14-2.—Flashlight tester.

prevent the flashlight from being used as an ordinary flashlight if desired. The tester may be made as follows:

1. Remove the lens holder from the rear of the flashlight and discard.
2. Remove the battery access from the flashlight.
3. Remove the spring and the spare bulb holder.
4. Mount the female test jack in the battery access cover.
5. Replace the spare bulb holder and solder the lug of the test jack to it.
6. Replace the spring and battery access cover of the flashlight.
7. Remove the reflector and holder from the front of the flashlight.
8. Drill hole and mount the female test jack approximately 1 1/8 inches from the front of the light 90 degrees clockwise from the light switch, looking at the front of the light.
9. Solder a 1 1/2 inch piece of wire to the terminal lug of the test jack.
10. Solder the other end of the short wire to the copper bar that connects the flashlight switch to the reflector.
11. Tape the terminal connection of the test jack to prevent its shorting to the positive contact spring.
12. Reassemble flashlight.

OHMMETER.—As mentioned above, the flashlight tester is an emergency instrument. The most desirable instrument for continuity checking is an ohmmeter (an ohmmeter contains its own batteries). With an ohmmeter, the resistance of an element can be determined directly by a scale. Discontinuity is indicated when the resistance between two points in the circuit is infinite, with the result that the needle is not deflected. The following paragraphs give a brief review of ohmmeter construction and operation. For more complete coverage, see Basic Electricity, NavPers 10086-A.

Testing Live Circuits

When live circuits are to be tested, the circuit under test is energized in a conventional manner by an auxiliary power unit or aircraft generator.

A voltmeter or test lamp is generally used. Make certain that the voltmeter used is designated for the type current (a.c or d.c.) to be tested and has a scale of adequate range. A test lamp should have low wattage and a voltage rating the same as the circuit being tested. A test lamp may be made by connecting two pieces of insulated copper wire to the terminals of a lamp receptacle and stripping about a quarter of an inch of insulation off the wire ends.

Extreme care must be taken when using this system of checking, as "live" points of the circuit will be exposed when junction box covers or connector plugs are removed. When a trouble has been located, remove all power from the circuit, make the necessary circuit repairs, reapply power, and then check for proper operation.

LOCATING TROUBLES

Likely sources of trouble are at electrical connections, especially connectors, and "blown" fuses or open circuit breakers. Loose contacts, corrosion, and chafing of insulation may sometimes be located by a visual inspection.

If a circuit breaker has tripped or a fuse has blown, a short caused by a ground is usually indicated. However, a high-resistance

or partial ground may result in low voltage in the circuit involved.

Tripped circuit breakers or blow fuses are not a sure indication of a ground. They are often tripped or blown by severe overloads. Another cause for a tripped circuit breaker or blown fuse is a short circuit other than a ground, although this is very uncommon.

To find circuit trouble in the shortest time, a good knowledge of circuit analysis is of maximum importance. To quickly locate trouble, the AE should become familiar with the electrical systems in the aircraft he is required to maintain. If an electrical test is necessary, the test must be closely observed to diagnose the probable troubles. Figure 14-3, in conjunction with table 14-1, illustrates this point.

When a unit is controlled by a relay, trouble can be in any one of four places—the relay circuit, the relay, the unit circuit, or the unit itself. Steps in checking for trouble are as follows:

1. Check circuit fuse, or circuit breaker, and unit fuse. If replaced fuse blows, check for ground or short circuit.

2. If fuses are good, listen for operation of the relay while an assistant operates the control switch. If the relay is inoperative, check the relay circuit. Trouble commonly occurs in relay contacts—in which case they must be cleaned or the relay must be replaced.

3. If the relay is operating, turn the control switch on and test for normal voltage at the input to the unit. Normal voltage at this point indicates that the trouble is in the unit itself.

4. If the voltage is not normal, check the unit circuit from the disconnect plug back to the power source.

Testing for Open Circuits

LIVE CIRCUIT.—Tests are made between a point or terminal in the positive side of the circuit and ground. Ground is any metallic part of the aircraft structure. Do not use as a ground an area that is painted or corroded. When making the test, hold or fasten one terminal of the test apparatus firmly to the point to be tested, and the other terminal firmly to the ground. Trouble is always located between the point showing full voltage or full light intensity and the point showing lower-than-normal voltage.

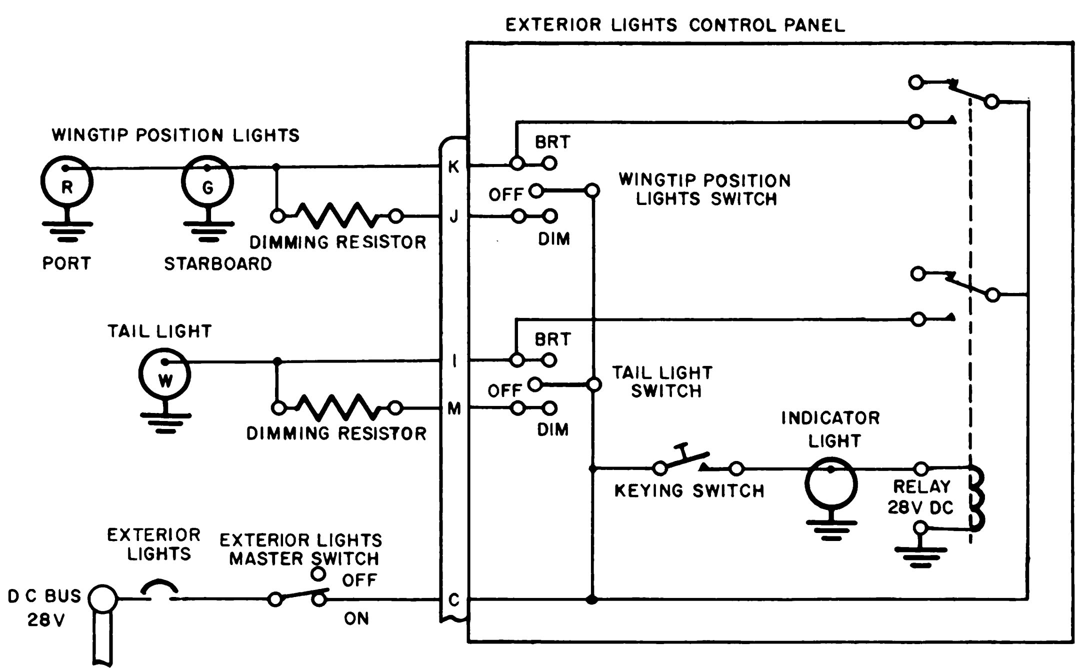


Figure 14-3.—Position lights (schematic).

Table 14-1.—Typical circuit troubles.

Defect	Probable circuit trouble	Location of trouble
Taillight fails to burn in "dim" position.	Open	1. At "dim" side of switch or 2. At pin M on control panel or 3. At dimming resistor.
Wingtip lights remain bright with switch in "dim" position.	Short	1. Pins K and J or 2. "Dim-bright" switch.
Exterior lights will not flash with keying switch; indicator light operates properly.	Open	1. Relay coil or 2. Open between points 0 and P.

In figure 14-4, the voltmeter reads normal voltage (24 v) when connected between ground and points A, B, C, D, and E. When the meter is connected between ground and point F, the voltage reading is zero, indicating an open between points E and F.

Always disconnect the power source when circuit connections are made or broken. Before beginning the test, disconnect the power source and the inoperative unit of the circuit. The latter should be disconnected so that the unit will not begin operating if the trouble corrects itself during the test. The unit can be disconnected by the connector or by breaking the circuit at any convenient point if the segment of the circuit between that point and the unit is not in question. Following this operation, connect the aircraft's battery to the electrical system and begin the test.

DEAD CIRCUIT.—First disconnect the aircraft's battery from the electrical system. Make a systematic point-to-point check in the segment of the circuit in which the trouble is suspected. (See fig. 14-5.)

When making this test, it is important that the suspected segment be totally isolated (electrically disconnected) from other circuits or loads. This will prevent the possibility of the continuity tester reading through other loads. If possible, the live circuit test should be used since it will simplify the procedure.

Testing for Grounds

LIVE CIRCUIT.—Determine that the circuits under test are deenergized by means of the current control switch or the battery master switch, or by disconnecting the battery.

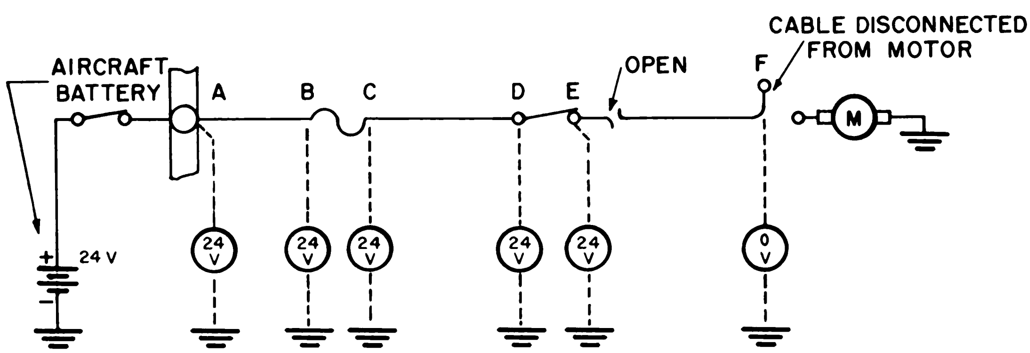


Figure 14-4.—Testing live circuit for an open.

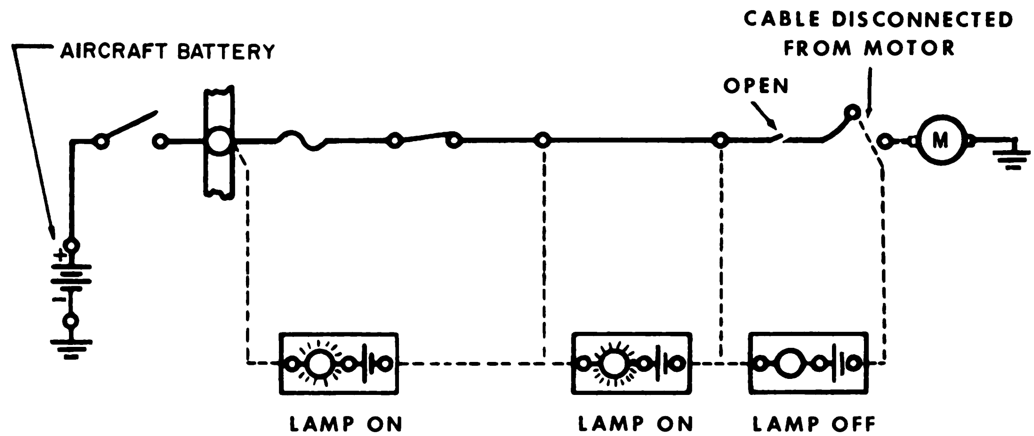


Figure 14-5.—Testing dead circuit for an open.

Also disconnect the inoperative unit from the circuit.

If the circuit is protected by a circuit breaker, turn the breaker off and connect the voltmeter across its terminals. If the breaker is of the type that may not be turned off, disconnect the wire lead from the load side of the breaker and connect the voltmeter between the load terminal of the breaker and the disconnected wire (fig. 14-6). If the circuit is protected by a fuse, remove the fuse and connect the voltmeter terminals to the fuse terminals or clips. An easy method of connection is by means of small battery clips attached to the voltmeter leads.

Disconnect all loads, such as motors or lamps, from the circuit. (See fig. 14-6.) These disconnections should be made as close to the equipment as possible. This prevents the meter from reading through these loads to ground after the trouble has been removed.

Energize the circuit. Unless the trouble has corrected itself, the voltmeter should show a reading. With circuit connections as shown in figure 14-6, the meter reads battery voltage because of the ground. If switch S is opened, the meter will not read, indicating the short is not between switch S and the circuit breaker. With switch S closed and the circuit broken at X, the meter also will not read, indicating the ground is not between switch S and terminal X. With the connection at X replaced and the circuit opened at Y, the meter will continue to read. This indicates that the ground is between X and Y. Unless the ground is severe, full voltage may not be indicated.

If the ground exists somewhere in a network of circuits, disconnect each circuit or branch of each circuit and check the voltmeter each time a circuit has been disconnected from the electrical system. When the

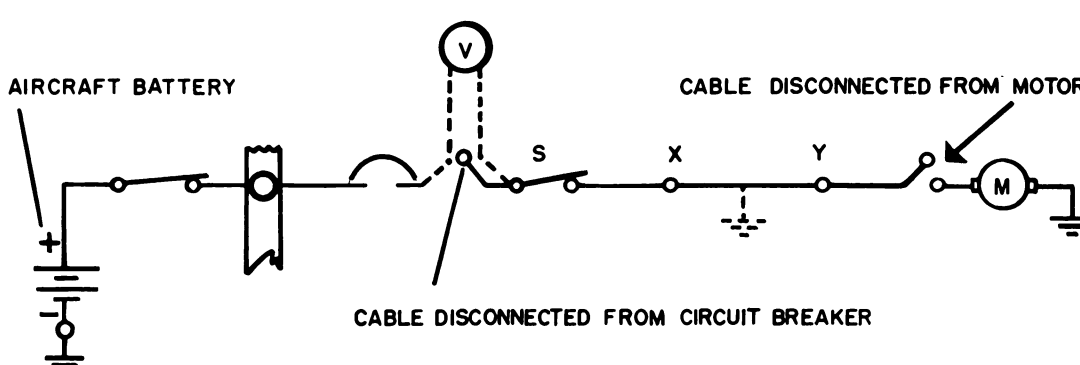


Figure 14-6.—Testing live circuit for grounds.

voltmeter ceases to indicate after a circuit has been isolated, the ground is in that circuit.

In the circuit of figure 14-3, for example, if the circuit breaker opens, a ground may exist anywhere between the circuit breaker and any of the lights. The ground could be isolated to one of the circuit branches by breaking connections at the control panel and observing a test voltmeter; it could also be isolated by observing the voltmeter as the individual switches are operated.

After the trouble has been isolated to a particular circuit, leave only that circuit connected to the electrical system.

Break the circuit at the next terminal or disconnect beyond the circuit breaker panel. If the circuit is clear (ungrounded) to that point, the test voltmeter will cease to register. If a ground is between the circuit breaker panel and the break in the circuit, the voltmeter will continue to register.

If the test voltmeter ceases to register at the first break, proceed to the next disconnect point and again check the tester. Continue this procedure until a point is reached at which the tester continues to indicate after a break. The ground will be between this point and the preceding one tested. (See fig. 14-6.)

DEAD CIRCUIT.—Disconnect the aircraft's battery and all other power from the system. Connect the leads of the ohmmeter as shown in figure 14-7. Then follow the same test procedure as for testing with live circuits.

Low Voltage Tests

Before testing a circuit for low voltage trouble, check the voltage of the power source to ascertain that normal voltage is being impressed across the circuit.

A low resistance in a high-current circuit would result in considerable voltage drop, whereas the same value resistance in a low-current circuit may be negligible.

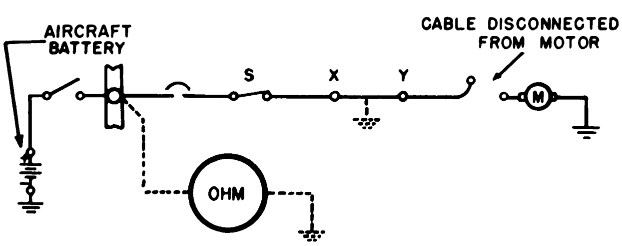


Figure 14-7.—Testing dead circuit for a ground.

Abnormal resistance in part of a circuit can be checked with either an ohmmeter or a voltmeter. Where practical, an ohmmeter should be used since the testing is then carried out with the circuit dead.

VOLTMETER METHOD.—Follow the procedure outlined previously for circuit testing of live circuits, but with the operating device connected in the circuit. Current greater than that drawn by a voltmeter must flow through a resistor or high-resistance connection in order to obtain a voltage-drop indication on a voltmeter. Check through the circuit until two successive points are located with low and normal voltage, respectively.

When making this test, it should be remembered that the voltage drops slightly with an increase in distance from the power source.

A test lamp can be used instead of a voltmeter if the voltage difference is great enough to be readily apparent on a test lamp. However, a voltmeter is preferable. In case of trouble at more than one point, the condition would be apparent on a voltmeter but might not show up on a test lamp.

When testing under the above conditions, extreme care must be taken as "live" points of the circuit will be exposed. It will sometimes prove advisable to remove all power from the circuit, make the necessary meter connections, then reapply power and observe the test indicator.

High Voltage Test

High voltage in a circuit is usually caused by a faulty voltage regulator or a short circuit to a higher voltage supply (for example, the 28-v d-c system may be shorted to the 115-v a-c system). The results of either of these could be recognized by blown fuses, tripped circuit breakers, burned insulation on wiring, or overheated motors and actuators.

The first step to be taken when abnormally high voltages are suspected in a circuit is to isolate the load from the power supply or the possible sources of high voltage. Fuses and circuit breakers should never be replaced before the possible sources of high voltage are shut down. After the equipment has been secured, check the affected circuits by following the steps already discussed for circuit troubleshooting (testing for shorts in a dead circuit).

Circuit Repairs

A defective wire must be either replaced or spliced with an insulated crimp style splice. When a new wire is installed, it must be of a type, length, and size in accordance with the specification on the wiring diagram.

When resetting a circuit breaker of the "non-trip-free" type, no power should be applied to the circuit. Where this is not practical, as may be the case with a switch type breaker, release the switch lever instantly so that the breaker can open if the overload condition still exists.

For information on crimp-on wire terminals, connectors, disconnects, lacing, emergency splicing, safety wiring, and waterproofing connectors, refer to chapter 4 of this training course.

USE OF METERS

Aviation electrical/instrument maintenance shops are equipped with various types of meters for the measurement of electrical quantities. They range in complexity from a simple plug-in ammeter to an electronic volt-ohm ammeter. The AE must exercise judgment in the selection of the proper test instrument to insure the desired results. He must not only base his selection on the type of meter and its operating ranges, but must also consider the effect the meter will have on the circuit being tested.

AMMETER

The ammeter used for routine maintenance of electrical/instrument equipment is normally specified by the Service Instruction Manual for the equipment. Since the ammeter has to be connected in series with the current path, circuits requiring frequent current readings or adjustments normally provide current jacks for use with a plug-in meter. Some equipments have a meter installed as part of the equipment, with a meter switch to provide the necessary ranges.

OHMMETER

The Navy does not normally supply its maintenance facilities with an instrument consisting solely of an ohmmeter. The ohmmeter is incorporated with the voltmeter to form a multimeter. Therefore, the choice of ohmmeter should be determined by the resistance ranges available in the various multimeters. Small multimeters, such as the TS-297/U, have a high range of R x 100; larger multimeters, such as the TS-352/U, have a high range of R x 10,000. The VTVM TS-505A/U has a high range of R x 1,000,000 and should be used where high values of resistance must be measured. When it is necessary to have high accuracy in the measurement of resistance, it is necessary to use a balanced-bridge instrument.

D-C VOLTMETER

The selection of a d-c voltmeter is normally based on the sensitivity of the meter movement and its effect on the circuit being tested. Meter sensitivity is discussed in Basic Electricity, NavPers 10086-A, and Basic Electronics, NavPers 10087-A.

A multimeter having low sensitivity may be used for quick, rough readings where approximations are adequate. When a high degree of accuracy is desired, a meter having high sensitivity is required. Such a meter has wide application in the maintenance of medium- and high-impedance electronic circuits found in aviation electrical/instrument systems.

A vacuum tube voltmeter, because of its high input impedance, is the ideal instrument for measuring low voltage in oscillators, automatic gain control, automatic frequency control, and other electronic circuits sensitive to loading. When measuring voltages in excess of 500 volts, a multimeter having a sensitivity of 20,000 ohms per volt will have an input impedance equal to or greater than most vacuum tube voltmeters. This can be proven by comparing input impedances of the two types of meters. The input impedance of most vacuum tube voltmeters is between 3 and 10 megohms. A 20,000-ohm-per-volt meter, when reading a voltage of 500 volts, would have an input impedance of 500 x 20,000 or 10 megohms. Therefore, on the 500-volt scale a multimeter of this sensitivity would have an input impedance at least equal to the vacuum tube voltmeter: For voltage readings over 500 volts, a 20,000-ohms-per-volt multimeter offers an input impedance higher than the vacuum tube voltmeter.

Any multirange voltmeter, though its sensitivity may not exceed 1,000 ohms per volt, can be used in an emergency to obtain reliable readings in a d-c circuit. If the impedance of

the circuit being tested is not known, a comparison of two voltage readings—one on the lowest usable range and the other on the next higher range—will indicate if the meter is having a loading effect on the circuit. If the two readings are approximately the same, the meter is not causing appreciable voltage variations and the higher reading may be accepted as the true voltage. If the two readings differ considerably, the true voltage may be found by the use of the following formula:

$$E = \frac{E_2 - E_1}{\frac{E_1 R}{E_2} - 1} + E_2$$

where

- E is the true voltage
- E_1 is the lower of the two voltage readings
- E_2 is the higher of the two voltage readings
- R is the ratio of the higher voltage range to the lower voltage range.

To illustrate the application of the correction formula, the following conditions are assumed:

1. A reading of 22 volts was obtained between two terminals with the meter on the 0-30 volt scale.
2. A reading of .82 volts was obtained from the same terminals when the meter was switched to the 0-300 volt scale.

The true voltage may be found as follows:

$$E = \frac{82 - 22}{\frac{22 \times 10}{82} - 1} + 82$$

$$E = 119 \text{ volts}$$

MULTIMETER

The AE is often required to measure voltage, current, and resistance when performing electrical maintenance. To eliminate the necessity of using more than one meter, the multimeter is used. The multimeter combines a voltmeter, ammeter, and ohmmeter in one unit. It includes all the necessary switches, jacks, and additional devices arranged in a compact, portable case utilizing one meter movement. Figure 14-8 illustrates a schematic diagram of a multimeter circuit.

The permanent-magnet, moving-coil meter mechanism is direct-current responding only. To adapt this mechanism for measuring a-c current and voltages, a rectifier (or a thermal converter for RF voltages) must be used to convert the alternating current to direct current.

The copper oxide type of rectifier used on many meters is compact, and has reliable accuracy for alternating waveforms with frequencies of 50 to 20,000 cps. Each rectifier plate in the rectifier assembly is made of copper with one side bare and the other coated with a layer of copper oxide. Plates of this character offer a low resistance when current seeks to flow in the copper to copper oxide direction, and a very high resistance when it flows in the direction of copper oxide to copper. Therefore, the alternating current is converted to direct current, and in that form is delivered to the meter mechanism. Copper oxide rectifiers are most commonly connected into full-wave bridge, double half-wave, and half-wave circuits.

At this point it is important to consider how the calibration of the meter is affected by the use of a rectifier. The permanent-magnet, moving-coil mechanism responds only to the average value of the current, which is not necessarily the same as the effective value.

Waveforms of various shapes have different average and effective values. Since this type of meter mechanism responds only to the average value, the shape of the waveform must be taken into consideration when the meter is calibrated for effective value. Thus, the meter reading is correct only on waveforms for which the meter was originally calibrated. In this respect, the instrument has a definite limitation because waveforms may vary considerably in conventional circuits. For example, the sine-wave voltage response of a half-wave rectifier is 32 percent of maximum for the average value, and 50 per cent for the effective value. The full-wave rectifier response is 64 and 71 percent, respectively. In the design of the meter, these values are taken into consideration, and the scales are plotted to read in effective units when calibrated against an accurate standard.

VACUUM TUBE VOLTMETER

The ordinary voltmeter has several disadvantages that make it practically useless for measuring voltages in high-impedance circuits.

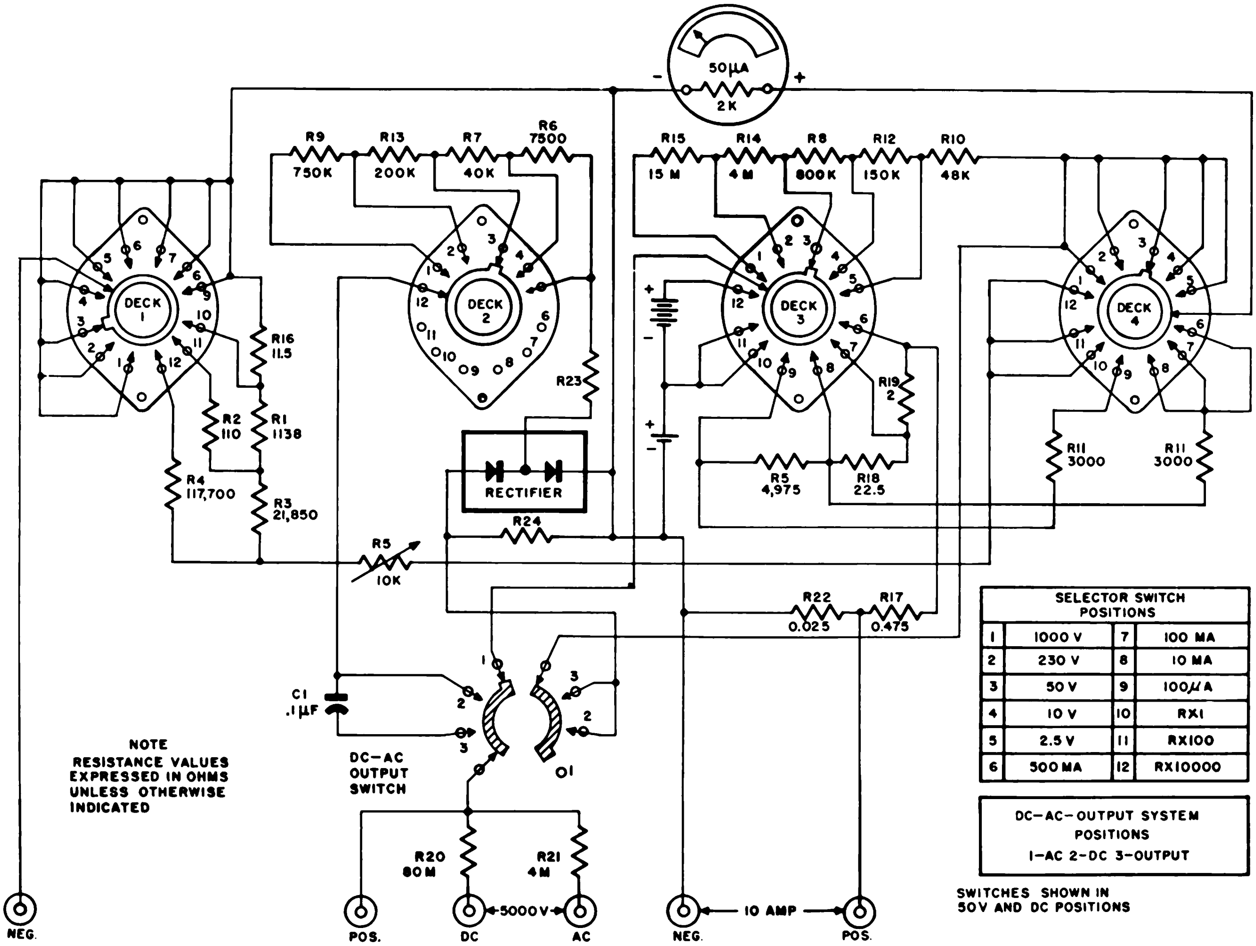


Figure 14-8.—Schematic diagram of a multimeter.

For example, suppose that the plate voltage of a pentode amplifier is to be measured. (See fig. 14-9.) When the meter is connected between the plate and cathode of the electron tube, the meter resistance, R_m, is placed in parallel with the effective plate resistance, R_{eff}, thereby lowering the effective plate resistance. The effective plate resistance is in series with the plate-load resistor, R_L, and this series circuit appears across the supply voltage, E_{bb}, as a voltage divider.

Since the overall resistance is lowered, the current through R_L will increase, the voltage drop across R_L will also increase, and the voltage drop across R_{eff} will decrease. The result is an incorrect indication of plate voltage.

Before the voltmeter is connected, the plate current is determined by the effective resistance of the plate circuit, the plate-load resistor, and the plate voltage. If the tube has an effective resistance of 100,000 ohms, R_L is 100,000 ohms, and the plate power supply is constant at 200 volts, then the plate current is 200v/200,000 ohms, or 0.001 ampere. The plate voltage (plate to cathode) is 0.001 x 100,000, or 100 volts.

Assume that the voltmeter used to measure the plate voltage of the tube has a sensitivity of 1,000 ohms per volt and that the selected meter range is from 0 to 250 volts. The meter will then have a resistance of 250,000 ohms. This resistance in parallel with the tube resistance of 100,000 ohms produces an effective resistance of 71,400 ohms in series with the

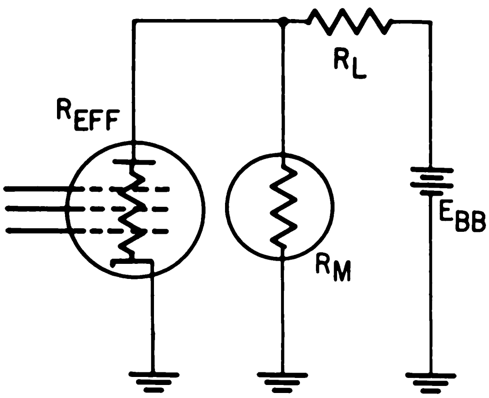


Figure 14-9.—Shunting effect of meter resistance.

plate-load resistor. The total resistance across the B supply is therefore 171,000 ohms instead of the 200,000 ohms before the meter was applied, and the current through the plate-load resistor is 200 v/171,400 ohms, or 0.00117 ampere.

Across the plate-load resistor the voltage drop is 0.00117 x 100,000 or 117 volts, and the plate-to-cathode voltage on the tube is 200-117, or 83 volts when the meter is connected. Thus, an error of 17 volts (17 percent in this case) results. The lower the sensitivity of the meter, the greater this error will be.

A meter having a sensitivity of 20,000 ohms per volt and a 250-volt maximum scale reading would introduce an error of about 1 percent. However, in circuits where very high impedances are encountered, such as in grid circuits of electron tubes, even a meter of 20,000-ohms-per-volt sensitivity would impose too much of a load on the circuit.

Another limitation of the nonelectric multimeter is the shunting effect of the metallic-oxide rectifier used in the a-c measuring section of the meter. This shunting effect becomes more pronounced as measured frequencies go up, due to the large capacitance of the recitifier plates. As pointed out previously, the metallic-oxide rectifier is limited to frequencies up to 20,000 cps.

This shunting effect may be greatly reduced by replacing the metallic-oxide rectifier with an electron tube rectifier. The rectified and filtered output of the diode is then applied to an amplifier tube that drives the meter. Such a device is called an electron tube voltmeter or a vacuum tube voltmeter, usually abbreviated VTVM. Figure 14-10 shows a schematic diagram of a VTVM.

The input impedance of a VTVM is large, and therefore the current drawn from the circuit whose voltage is being measured is small, and in most cases negligible. This enables the AE to measure a voltage in a high-impedance circuit without danger of excessively loading the circuit and introducing errors in the reading. Table 14-2 shows the relative circuit loading effect of a nonelectronic voltmeter as compared with that of an electronic voltmeter (VTVM).

SEMICONDUCTORS

The semiconductor has been used commercially for a number of years; however, it has been only in the last half of this century that they have been used extensively in military equipment. Semiconductors are the basic components of transistors; therefore, it is necessary for the AE to understand the basic fundamentals of semiconductors.

For a thorough understanding of the principles of semiconductors and transistors, the AE should review the pertinent chapters in Introduction to Electronics, NavPers 10084, and Basic Electronics, NavPers 10087-A.

Although generally more rugged than the electron tube, semiconductors are sensitive to electrical shock, heat, humidity, and excessive radiation.

PRECAUTIONS IN USING AND HANDLING SEMICONDUCTORS

Some electrical tools such as wire wrappers and some types of soldering irons produce transient voltages each time their power is switched on or off. These transients are produced by the inductive reactance developed within the tool and in the ground leads. Often these transients exceed the voltage that may be safely applied to the semiconductor device. Should this happen while the tool is in contact with the transistor, these transient voltages could cause permanent damage to the semiconductor. Caution should therefore be exercised when switching power on or off. If it is not practical to remove the tool from contact with the device before actuating the power switch, the tool must be equipped with an electrical filter to protect the semiconductor device, and the tool must be properly grounded.

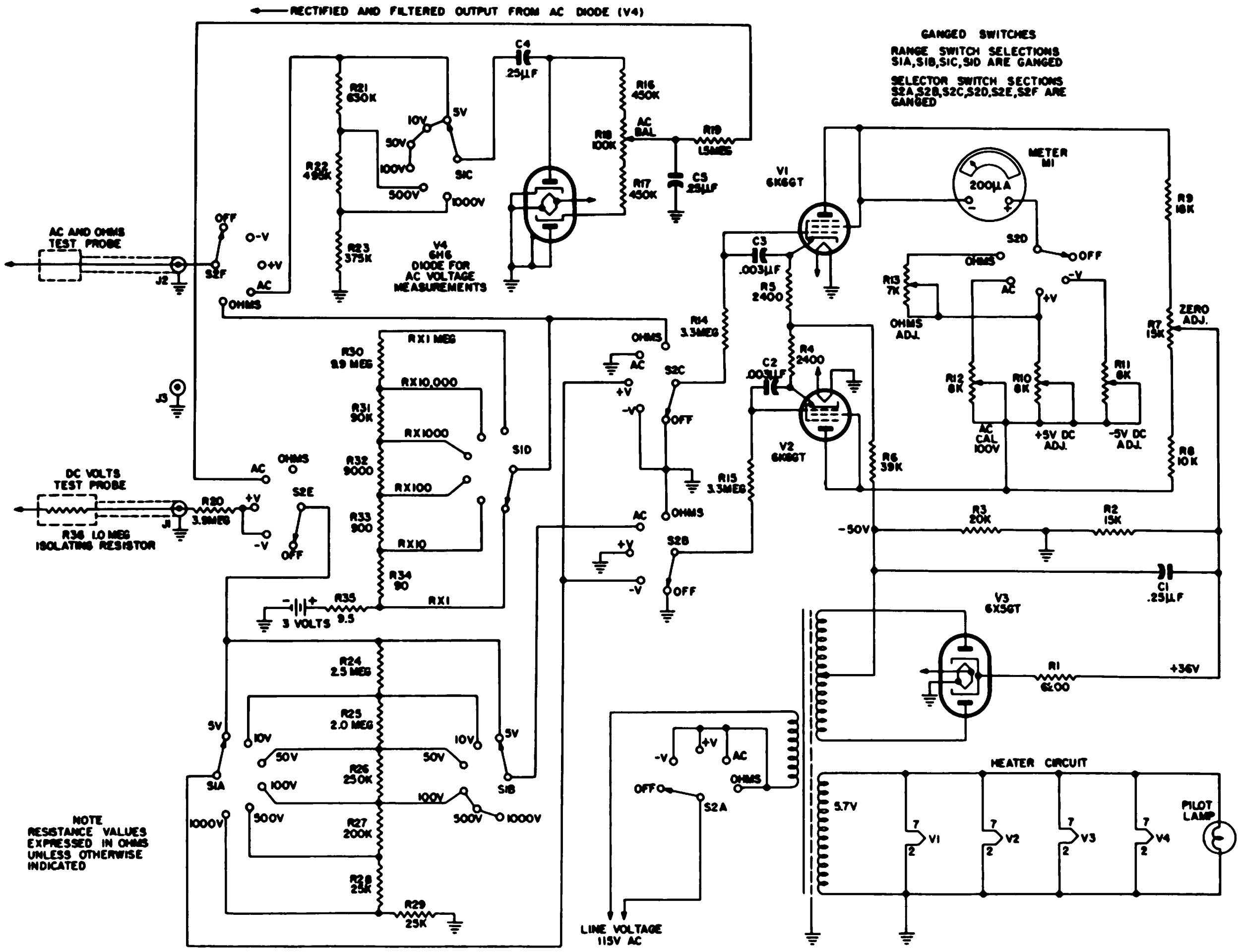


Figure 14-10.—Schematic diagram of a typical VTVM.

An ordinary soldering iron can have leakage voltage present on its tip. This leakage voltage could easily cause the junction of the semiconductor to break down and destroy its characteristics. Since semiconductors are low voltage devices, only soldering irons which are safely isolated from high line voltages should be used.

Many circuits using transistors are of the constant-current type; that is, when the circuit operates with the device removed, the terminal voltage may rise to full voltage of the power supply. If the transistor is inserted into a line circuit of this type, the high voltages present will do permanent damage to the semiconductor. To avoid this hazard, turn off all power before installing the semiconductor into the circuit. Should the circuit use more than one supply voltage, ascertain if there is a specified sequence for applying and/or removing power. A good rule is to be sure all power is off before the semiconductor is installed. Since the semiconductor can be permanently damaged if the wrong voltages happen to reach its terminals, care should be exercised while "probing" a circuit. One slip could cause a momentary short circuit that could easily destroy valuable equipment.

Ordinarily a pair of diagonal pliers are used to cut common electrical wires; however, a cutting tool of this type should not be used on transistors. The mechanical shock produced by such cutting action would travel into the semiconductor and weaken or destroy the delicate connections.

The proper way to shorten or cut the leads of a semiconductor is to use a shearing type tool

Table 14-2.—Circuit loading effect—VTVM vs. nonelectronic voltmeter.

Range (volts)	Input resistance		Circuit loading effect
	VTVM	Nonelectronic voltmeter*	
5	10 megohm	0.1 megohm	Nonelectronic voltmeter 100 times that of VTVM.
10	10 megohm	0.2 megohm	Nonelectronic voltmeter 50 times that of VTVM.
50	10 megohm	1.0 megohm	Nonelectronic voltmeter 10 times that of VTVM.
100	10 megohm	2.0 megohm	Nonelectronic voltmeter 5 times that of VTVM.
500	10 megohm	10.0 megohm	Nonelectronic voltmeter same as as that of VTVM.
1,000	10 megohm	20.0 megohm	Nonelectronic voltmeter one-half that of VTVM.

*Nonelectronic voltmeter—20,000-ohm-per-volt type.

and a mechanical shock dampener. A pair of surgical scissors make a satisfactory shearing tool. The mechanical shock can be reduced to safe level with a pair of flat-nosed pliers inserted between the semiconductor and the shearing point.

Many semiconductors are hermetically sealed in glass to improve reliability of operation. The leads of the semiconductor are often plated to improve conductivity and to make soldering easier. These provisions create maintenance problems because the delicate seal may be cracked or broken if the leads are bent too close to the semiconductor device. In addition, if the leads are bent too sharply, the plating material may be damaged. This bending of the leads could be done by an inexperienced AE, while attempting to force the semiconductor into the wrong type socket or guide hole.

Semiconductors, when received from supply, have their leads wrapped in gummed tape for protection. If the tape is pulled from the leads while holding to the body of the device, a strain will be exerted upon the glass-to-metal seal. This strain may weaken the connections inside the device or break the leads. Caution should therefore be exercised while removing this packaging tape.

Semiconductors received from supply and awaiting use should be stored in a storage area of normal room temperature and humidity. The area selected should also be free of radiation and magnetic fields, as these too can damage or shorten the effective life of semiconductors.

The electrical characteristics of semiconductor devices change rapidly with a change in operating temperature. For this reason, it is important that tests be performed at the specified ambient temperature. Tests performed at the wrong temperature may cause good semiconductors to check bad and those which are defective to check out as good. To insure validity of test results for units using semiconductors, be sure the ambient temperature is approximately 77° F ±5°.

PRINTED CIRCUIT MAINTENANCE

The maintenance of printed circuit board assemblies requires a suitable work area and adequate tools, equipment, and materials. The work area must be large enough to accommodate workbenches, storage cabinets, test equipment, and materials, and still leave adequate space to provide uncrowded work areas. The area should be further assigned into a specific area for troubleshooting, repair and replacement, protective coating application, and storage. The area should be enclosed and air conditioned to prevent

the contamination of the circuit board assemblies by dirt and moisture.

Cleanliness and humidity control are two very important factors in circuit board maintenance. Lighting is another important requirement. Due to the miniaturization and close spacing of circuits and components, maintenance requires good overhead lighting with provisions for adjustable lighting on the workbenches.

The storage area is used for the storage of circuit board assemblies, tools, equipment not in use, materials for the protective coating process, records, related maintenance publications, and materials and parts required for the repair operation. Storage for the circuit boards must be capable of holding the circuit boards in a vertical position. The parts are exposed and easily damaged; therefore, they should be stored separately and in a vertical position. The storage of some protective materials may require refrigeration.

The troubleshooting and repair area should consist of a bench area equipped with an adjustable light fixture with magnifying glass and a pegboard (or similar fixture) for storing tools in an easily accessible manner. A complete assortment of handtools, soldering irons (with desoldering accessories), soldering aids, and a variety of heat sink tools are required for printed board maintenance. A suitable holding fixture should be available for holding the circuit board during repair.

The area set aside for the application of the protective coating should include a bench area with an adjustable holding fixture with suitable lighting. It should also include an exhaust fan or hood over the bench area and a low pressure source (15 psi) of filtered air. An assortment of small items such as mixing cans, stirring paddles, brushes, dipping vats, lint-free cloth, spray guns, etc., will be needed. The extent of the provisions is determined by the type of protective coating prescribed by the manufacturer. A washbasin should be provided for the purpose of washing off any of the materials used in the coating process which come into contact with the skin. Some of these materials are possible irritants to the health of the individual.

Although the troubleshooting procedures for printed circuits are similar to those for conventional circuits, the repair of printed circuits requires considerably more skill and patience. Printed circuits are small and compact; thus personnel should become familiar with the special servicing techniques required.

In all instances, it is advisable to first check the defective printed circuit before beginning work on it to determine whether any prior servicing has been performed. Not all personnel having access to this type of equipment have the skill and dexterity required; hence some preliminary service may be necessary. By observing this precaution you may save a great deal of time and labor.

The defective part should be pinpointed by a study of the symptoms and by careful and patient analysis of the circuit before attempting to trace trouble on a printed circuit board. Ascertain whether the conducting strips are coated with a protective lacquer, epoxy resin, or similar substance. If so, carefully scrape it away or, better still, use a needle or chuck type needle probe, as shown in figure 14-11, which will easily penetrate the coating for continuity check.

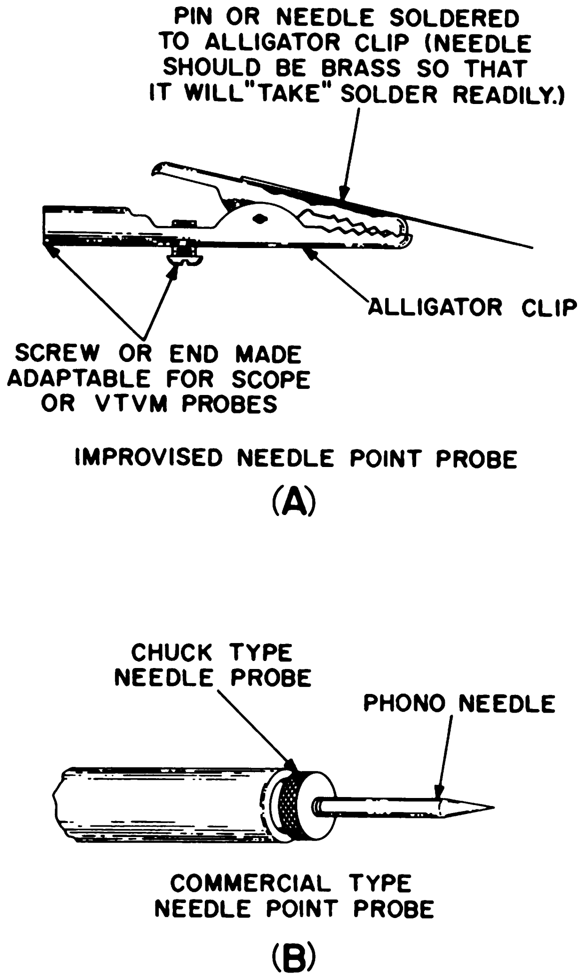


Figure 14-11.—Needle probes.

Breaks in the conducting strip (foil) can cause permanent or intermittent trouble. In many instances, these breaks are so small that they cannot be detected by the naked eye. These almost invisible cracks (breaks) can be located only with the aid of a powerful hand- or stand-held magnifying glass, as illustrated in figure 14-12.

The most common cause of an intermittent condition is poorly soldered connections. Other causes are broken boards, broken conducting strips, fused conducting strips, arc-over, loose terminals, etc.

To check out and locate trouble in the conducting strips of a printed circuit board, set up a multimeter (one which does not pass a current in excess of 1 ma) for making point-to-point resistance tests, as shown in figure 14-13, using needle point probes. Insert one point into the conducting strip, close to the end or terminal, and place the other probe on the terminal or opposite end of the conducting strip. The multimeter indicates an open circuit, drag the probe along the strip (or if the conducting strip is coated, puncture the coating at intervals) until the multimeter indicates continuity. Mark this area and then use a magnifying glass to locate the fault in the conductor (fig. 14-12).

CAUTION: Before using an ohmmeter for testing a circuit containing transistors or other voltage-sensitive semiconductors, check the current it passes under test on all ranges. Do not use a range that passes more than 1 ma.

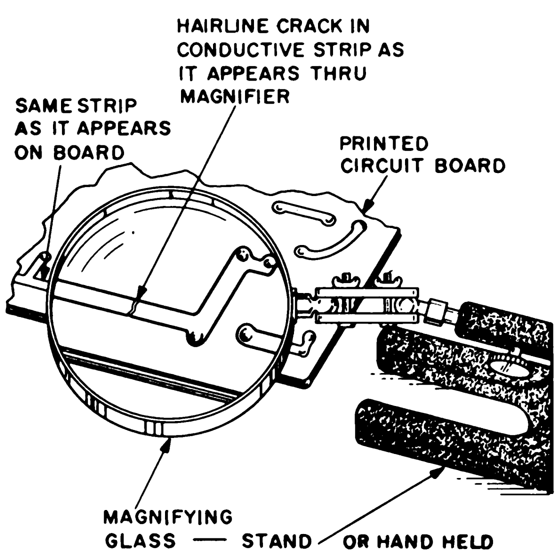


Figure 14-12.—Using a magnifying glass to locate a hairline crack.

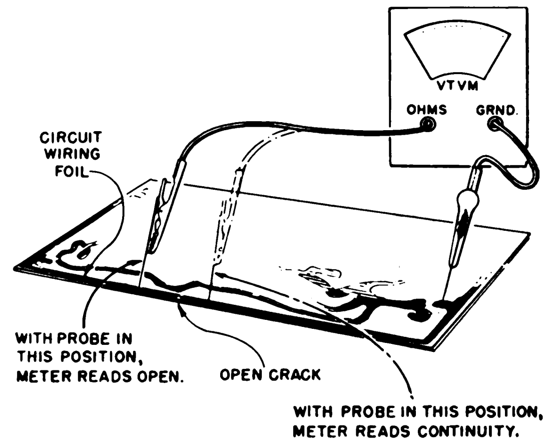


Figure 14-13.—Using a VTVM to locate a break in a conductive strip.

If the break in the conducting strip is small, lightly scrape away any coating covering the area of the conducting strip to be repaired. Clean the area with a firm-bristle brush and approved solvent (see Handbook of Cleaning Practices, NavShips 250-342-1), then repair the cracked or broken area of the conducting strip by flowing solder over the break (fig. 14-14(A)). If there is any indication that the strip might peel, bridge the break with a small section of bare wire (approximately 2 inches) by the method shown in figure 14-14(B). Apply solder along the entire length of the wire to bond it solidly to the conducting strip. Considerable care must be exercised in applying the solder to prevent it from flowing onto or near an adjacent strip. Keep the solder within the limits of the strip that is being repaired.

If a strip is burned out, or fused, cut and remove the damaged strip. Connect a length of insulated wire across the breach or from solder point to solder point (fig. 14-14(C)).

It is best not to glue or bond a conducting strip that has been lifted or peeled from the board at a terminal or solder point. Instead, clip off the raised section and replace it with insulated hookup wire from solder point to solder point.

Printed circuit boards are frequently subject to leakage and shorts, especially if the spacing between conductors is very close, or by the careless formation of a solder bridge between the conducting strips during soldering. NOTE: After repairs, always scrutinize the board for solder droppings that may cause possible shorts.

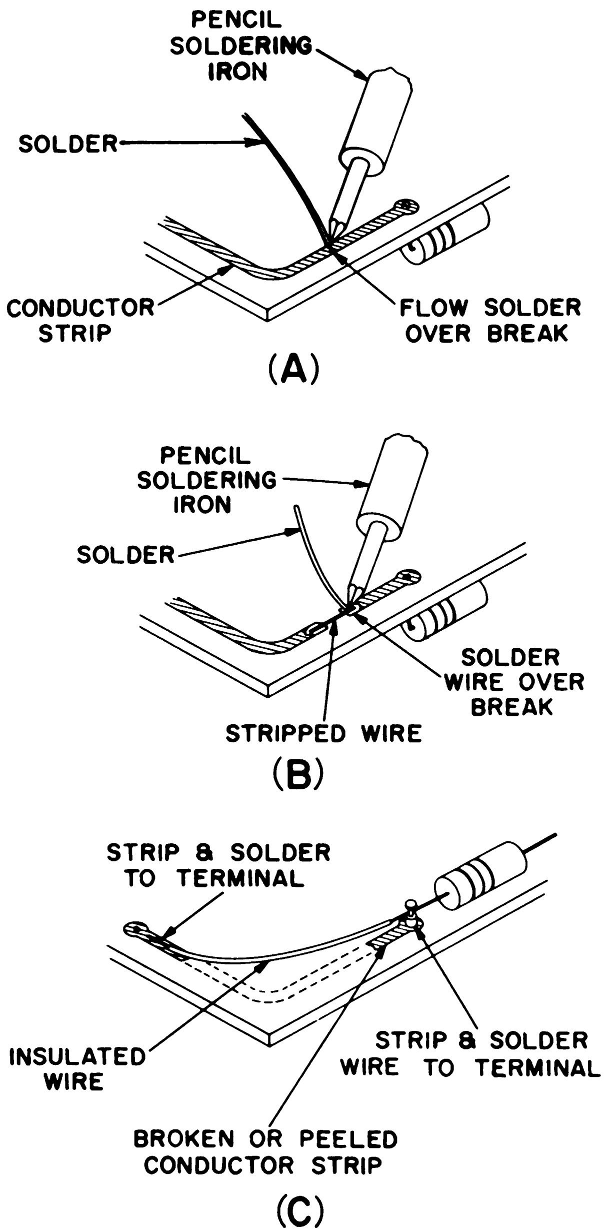


Figure 14-14.—Three methods of repairing broken conducting strips.

Frequently, a low-resistance leakage path is created by moisture and/or dirt that has carbonized onto the phenolic board. This leakage can be detected by measuring the suspected circuit with a multimeter. To overcome this condition, thoroughly clean the carbonized area with solvent (methyl chloroform GM 6810-664-0387) and a stiff brush. If this does not remove it, use a scraping tool (spade end of a solder aid tool or its equivalent) to remove the carbon, or drill a hole through the leakage path to break the continuity of the leakage. When the drilling method is used, be careful not to drill into a part mounted on the other side.

Occasionally, a conductor will rupture or fuse, usually because of a current overload. Generally, the rupture, or fusing, is the result of limited spacing and narrow conductors. Do not try to repair this type of damage, other than to bridge the rupture, or fused area, with a length of insulated wire (fig. 14-14(C)).

Most printed circuit boards have areas of conduction, known as grounding conductors, at each edge of the board or on the parts-mounted side of the board. These grounding conductors are conducting strips, used for grounding parts and as a mounting contact for the chassis or common ground. Sometimes an intermittent condition will result if the grounding screws or mounting screws become loose. If this occurs, tighten the screws and then solder a good bond directly from the grounding strip to the chassis or equipment ground. If this is not practical, bond the screws (after tightening) with an epoxy resin or similar compound.

The most common cause of broken boards is droppage. Some boards are broken because of careless handling by service personnel while the equipment is under repair. Be extremely careful at all times while handling a board. Do not flex the board indiscriminately; be especially careful when removing the board or replacing parts; do not force anything associated with the board.

A printed circuit can be flexed to a certain extent; however, flexing may break the board which must then be replaced at a considerable loss of time. To prevent this possibility, it is always good policy to use a chassis-holding jig or vise when servicing printed boards.

Before repairing a broken printed circuit board, assess the damage. Inspect the condition of the board and the extent of the break. If the board is not too complicated or the damage not too extensive, the board can probably be repaired.

After the repairs are completed, clean the repaired area with a stiff brush and solvent. Allow the board to dry thoroughly, and then coat the repaired area with an epoxy resin or similar compound. This coating not only will protect the repaired area but will help to strengthen it.

NOTE: When a board is broken, it is much better to replace the entire board. The repair techniques given above are for temporary repair only.

SPECIAL TECHNIQUES

It is always desirable to replace parts on a printed circuit board without applying heat directly to the conducting strip. This procedure prevents damage to the printed circuit conductors, feed-thru devices, eyelets, or terminals, and saves time in repair. It also prevents damage to semiconductors and other heat-sensitive parts that may be in proximity to the part being repaired.

Replacing parts requires that each type of part mounting be considered individually for the best method of removal.

A part to be removed may be too close to a heat-sensitive semiconductor or other part to allow the hot pencil soldering iron to be applied. A quick test to determine this safe distance is to place your finger between the semiconductor (or heat-sensitive part) and the part to be removed. Place the hot soldering iron in the position to be used. If the heat is too great for your finger it is too hot for the semiconductor. After determining that the heat-sensitive part is too close, place a shield (asbestos or like substance) between the parts before applying the hot soldering iron, and place heat sink clamps on all leads from the heat-sensitive part.

Solid-state parts and their associated circuitry are extremely sensitive to thermal changes. Therefore, particular care must be taken to prevent exposing them to heat. Heat sink and shunts must be applied with shields inserted to protect the associated parts any time repair or removal of a part requires the use of a hot soldering iron. Solid-state parts and associated assemblies require the same care in handling and skill of repairing that is applied to assemblies in equipment of unitized or modular construction containing transistors, tantalum capacitors, crystals, etc.

Removal of an axial-lead part that has been bonded to a printed circuit board (with an epoxy resin or similar compound) can be accomplished by breaking the defective part or by applying heat to the bonding compound. The method to be used depends upon the part itself and its location.

If the defective axial-lead part cannot be removed by heat, cut or break the part away from the bonding compound. Figure 14-15

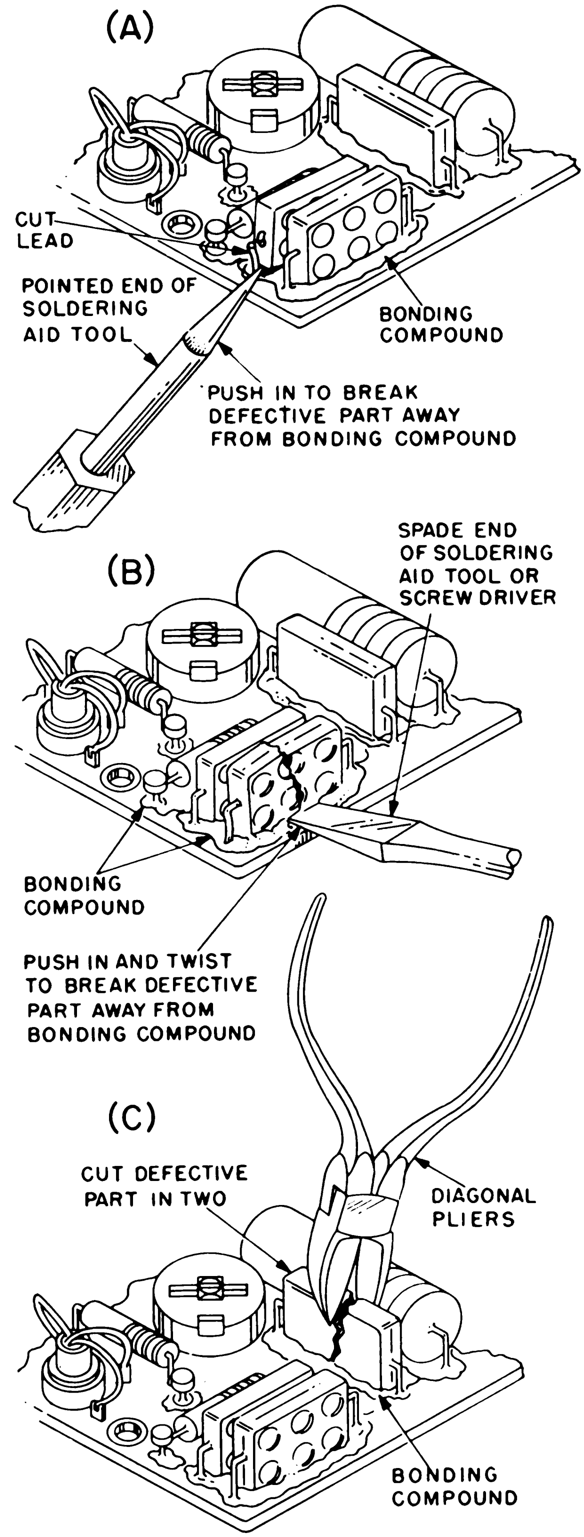


Figure 14-15.—Removing a defective part from bonding compound.

illustrates two different methods of breaking the part away from the bonding compound where the part is too close to other parts to use cutting pliers. In some instances, the part to be replaced is so closely positioned between other parts that one lead must be cut close to the body of the defective part to permit application of the prying tool. Wherever possible, cutting the defective part with end cutting pliers or diagonals, as shown in part (C), is the preferred method to use.

Regardless of which tool is employed (round-pointed or spade type), great care must be used in its application to prevent the printed circuit board or other parts from being damaged or broken. Apply the point of the tool against the bonding compound, between the part and the printed circuit board. Use the tool in such a manner that it works away the bonding compound from the part to be broken away until enough has been removed for the tool to exert pressure against the part. Keep the leverage surface area of the tool flat against the surface of the printed circuit board; this helps to prevent the tool from gouging or breaking the board.

CAUTION: Never apply much pressure against a printed circuit board.

After the defective part has been removed from the bonding compound, remove the leads or tabs from their terminals on the printed circuit board. Clean the area thoroughly before installing the new part. Do not remove the compound left on the board under the removed part unless its condition requires it. The mold left in the compound should be the same as the new part; thus, inserting the new part in this mold helps to secure it from vibration. After the repairs have been completed and the circuit tested, spray the newly soldered area with an insulating varnish or equivalent. Coat the new part or parts with a bonding compound (ECCOBOND "55" by Emerson and Cuming, Inc.; relix-R-313 by Carl H. Briggs Co.) or equivalent.

To replace a proven defective transistor, first cut all of its leads, and then remove it from the assembly. Transistors are mounted on circuit boards in many different ways; thus it is necessary to study how a particular transistor is secured before attempting to remove it. A transistor with clamp type mounting requires only a pointed tool between the clamp and the transistor to remove it. A transistor mounted in a socket may have a wire or spring clamp around it. Remove this clamp before pulling the transistor out of the socket. In some instances the transistor is bolted through the board. Remove the nut and washer, then remove the transistor. Where vibration is a prime factor, the manufacturer mounts the transistor through the circuit board and bonds it (with epoxy resin or similar compound). For this type, a flat-ended round-rod type tool (drift punch) of a diameter less than that of the transistor case is required. Be sure that the printed circuit board on which the transistor is mounted is secured in a proper device, and in such a way that pressure exerted against the board is relieved by a proper support on the other side (fig. 14-16). Apply a hot pencil soldering iron to the bonding compound and simultaneously apply the drift punch against the top of the transistor, exerting enough pressure to remove the transistor from the softened compound, and then on through and out the board (fig. 14-16).

Before installing the new transistor, great care must be taken to prepare the part for installation.

Test the transistor in a transistor tester (TS-1100/U or equivalent) before installing. This precaution will assure that the transistor is good before it is installed. For several reasons transistors can and do become defective in storage. Therefore, always check them before installation.

Preshape and cut the new transistor leads to the shape and length required for easy replacement. Use sharp cutters, and do not place undue stress on any lead entering the transistor. The leads are fragile, and are therefore susceptible to excessive bending or too sharp a bend. Shape any bend required in a gradual curve, and at least 1/4 inch to 3/8 inch from the base of the transistor. A safety measure which can be taken to insure that the lead will not break off at the base is to use two pairs of needle nose pliers. With one pair grasp the lead close to the transistor base, while shaping the rest of the lead with the other pair.

NOTE: The above procedure and precaution should be applied to any and all semiconductors, tantalum capacitors, and other miniaturized parts in equipment of modular or unitized construction.

After the remaining pieces of the defective transistor-terminal leads have been removed and the terminals on the board cleaned and prepared, connect the new transistor to its proper terminals.

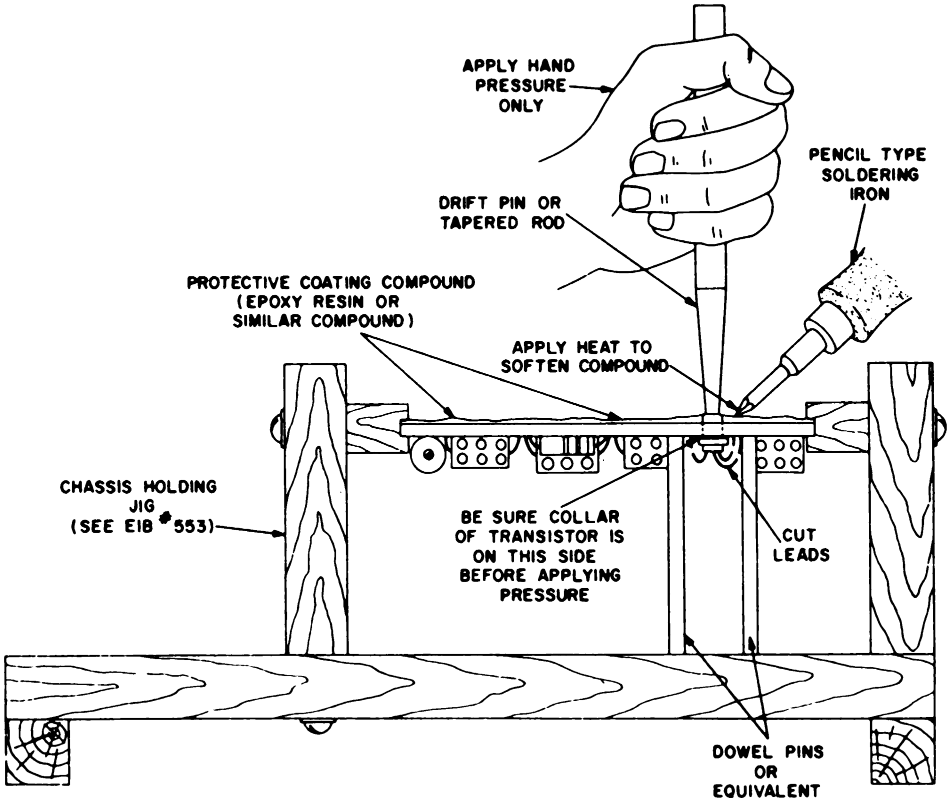


Figure 14-16.—Removing a transistor that has been through-board mounted.

REMEMBER: Handle any semiconductor or miniaturized part carefully; be gentle and be precise.

When the defective transistor is removed from a through-board mounting and bonded, care must be taken that the new transistor clears the hole before it is connected to its terminals. If the hole is too large, shim it with a thin plastic sleeve (fabricated). If the hole is too small, ream it to accept the new transistor. Rebond the fitted transistor after testing the repaired circuit, and it is proven to be operative. CAUTION: Do not use heat to rebond replaced semiconductors.

To remove and replace a multilug part, such as a transformer, choke, filter, or other similar potted, canned, or molded part, release the part from its mounting before disconnecting or cutting its conductors. Before applying pressure to remove such a part, inspect it carefully to be sure that the part is completely free of all its connections to the printed circuit board, and that all bent or twisted mounting lugs have been straightened; otherwise, the board may be broken. Never wrench or twist a multilug part to free it, because this will cause the conducting strip to become unbonded from the board. Work this type of part in and out in line with its lugs, while applying a hot pencil soldering iron (fig. 14-17 (A)), using a bar type tiplet adapter or similar desoldering tool.

Whenever possible, cut the conducting or mounting leads and lugs of the defective multilug part on the mounting side of the board (fig. 14-17 (B)). Heat and straighten the clipped leads with a hot pencil soldering iron and slotted soldering aid tool (or slotted soldering iron tiplet adapter or similar desoldering tool) applied to the circuit side of the board; pull the leads or tabs through with pliers as shown in part (C) of figure 14-17.

To replace the new multilug part, check to be sure that all of the lead holes or slots are free and clean, allowing easy insertion of the multilug part. Do not force any part into position on a printed circuit board, because the board might break or the printed circuit strip

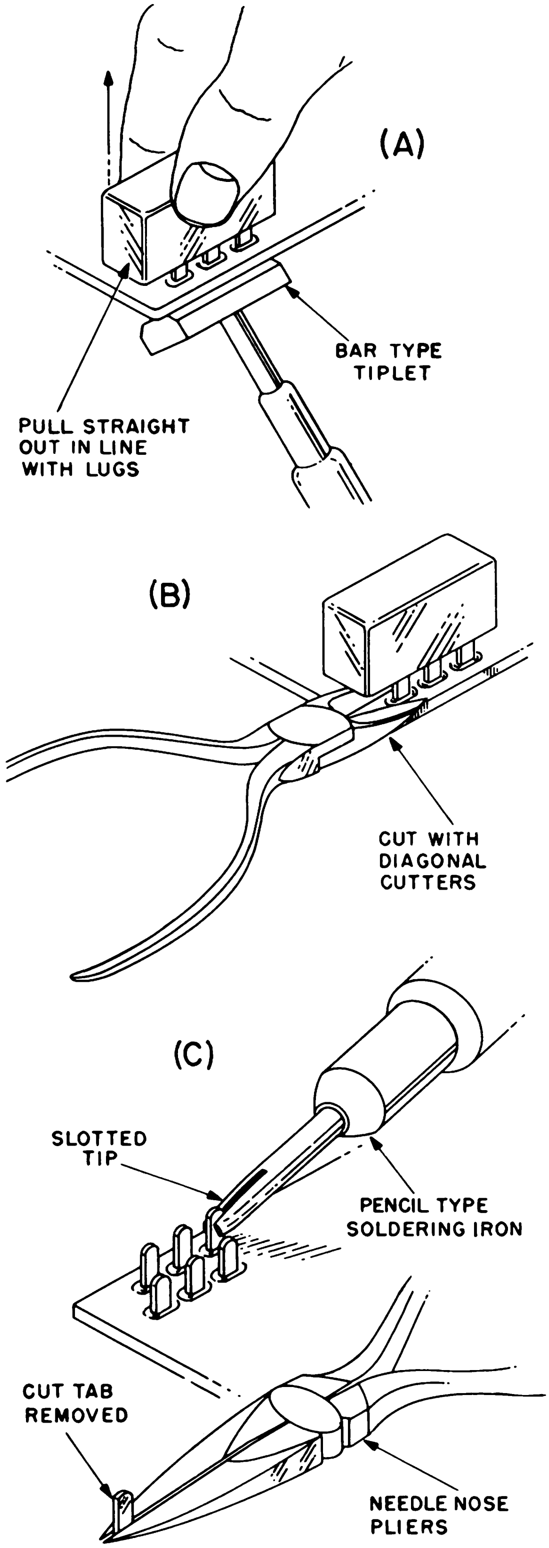


Figure 14-17.—Removing a defective multilug part.

and eyelet terminal lift. If the part does not position easily, check and rework the terminals and holes (or slots) until it does seat freely; then proceed to solder.

Be very careful when replacing defective parts that have leads terminating on standoffs, feed-thru terminals, etc. In most instances, standoffs and feed-thru terminals, are very small, and mounted on a thin phenolic board; thus they are susceptible to damage by heat and undue pressure.

EMERGENCY TECHNIQUES

In many instances there is a need for a time-saving technique and procedure for electronic assembly emergency repair. It is desirable, when making an emergency repair, to avoid unnecessary disassembly to expose the defective part when testing and/or repairing. In many instances this can be accomplished by removing only the cover from the assembly.

To remove and replace an axial-lead part (a part mounted by leads that extend from each end, such as a common resistor or capacitor), cut the leads as close as possible to the body of the part, and then connect the leads of the replacement part to the leads remaining on the board. The cutting is accomplished with a pair of end cutting pliers (fig. 14-18 (A)). Clean and straighten the leads remaining on the board. Fashion small loops in the leads of the replacement part (fig. 14-18(B)), making the loop size and lead length such that the loops slip easily over the leads projecting from the board. Secure these connections by bending the old leads away from the part. Place a heat sink clamp on the lead from the board, between the board and the connection to be soldered, and then solder the connection (fig. 14-18 (C)). The heat sink prevents the leads connected to the board from becoming unsoldered and causing a short, or open circuit. Always check to be sure that the old leads are properly connected to the conducting strip.

If cutting the leads of a defective axial-lead part would result in leads that are too short for the replacement part to be connected properly, cut the faulty part in half with a pair of diagonal or end cutting pliers (fig. 14-19 (A)). Then carefully cut away the pieces of the part from each lead (fig. 14-19 (B)). This will yield leads of sufficient length to permit the replacement part to be fitted and soldered as shown in figure 14-18 (C).

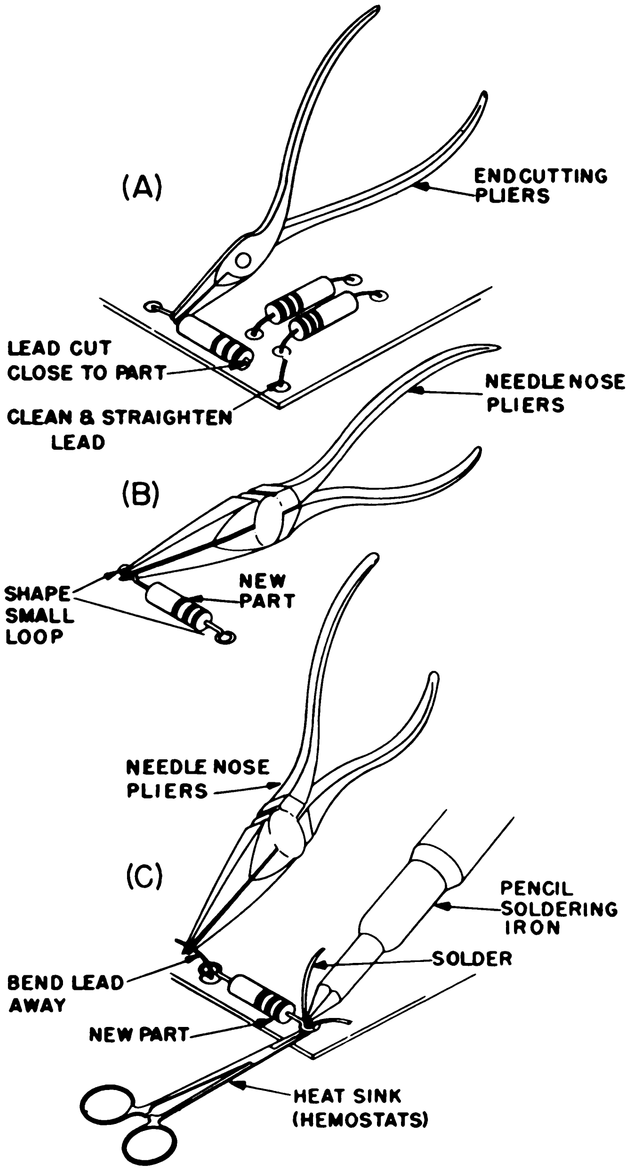


Figure 14-18.—Replacing a defective part by cutting its leads.

Considerable care must be taken when replacing a defective part that terminates on miniaturized standoffs, feed-thru terminals, etc. These small terminals break easily from applied pressure, or they may melt loose from excessive application of the hot soldering iron. Do not attempt this type of repair on an assembly unless there is no replacement available.

For emergency or temporary repair purposes, the following techniques may be used. Cut the lead close to the defective part (fig. 14-20 (A)). Use a heat sink clamp (or pliers)

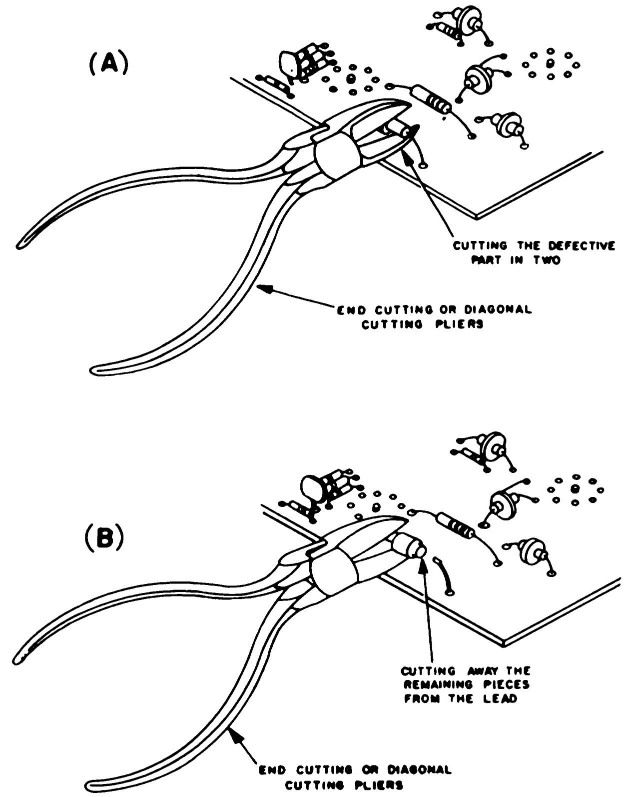


Figure 14-19.—Cutting the defective part for maximum lead length.

next to the terminal, then solder a spliced lead from the terminal to the new part (fig. 14-20 (B)).

A helpful heat control technique is to place a small piece of beeswax (W9160-253-1172) on the terminal behind the heat sink. When the beeswax melts, the temperature limit has been reached. This is a warning to remove the source of heat immediately. Allow the area to cool thoroughly before attempting to complete the soldering of the connection. Apply a new piece of beeswax to the terminal, repeating this procedure until the connection is satisfactorily soldered.

It is best not to glue or bond a conducting strip on a printed circuit board that has been lifted or peeled from the board at a terminal or solder point. Instead, clip off the raised section and replace it with insulated hookup wire from solder point to solder point. However, for temporary or emergency repair, a loose or peeled strip may be bonded back onto the board, using a non-conductive bonding compound

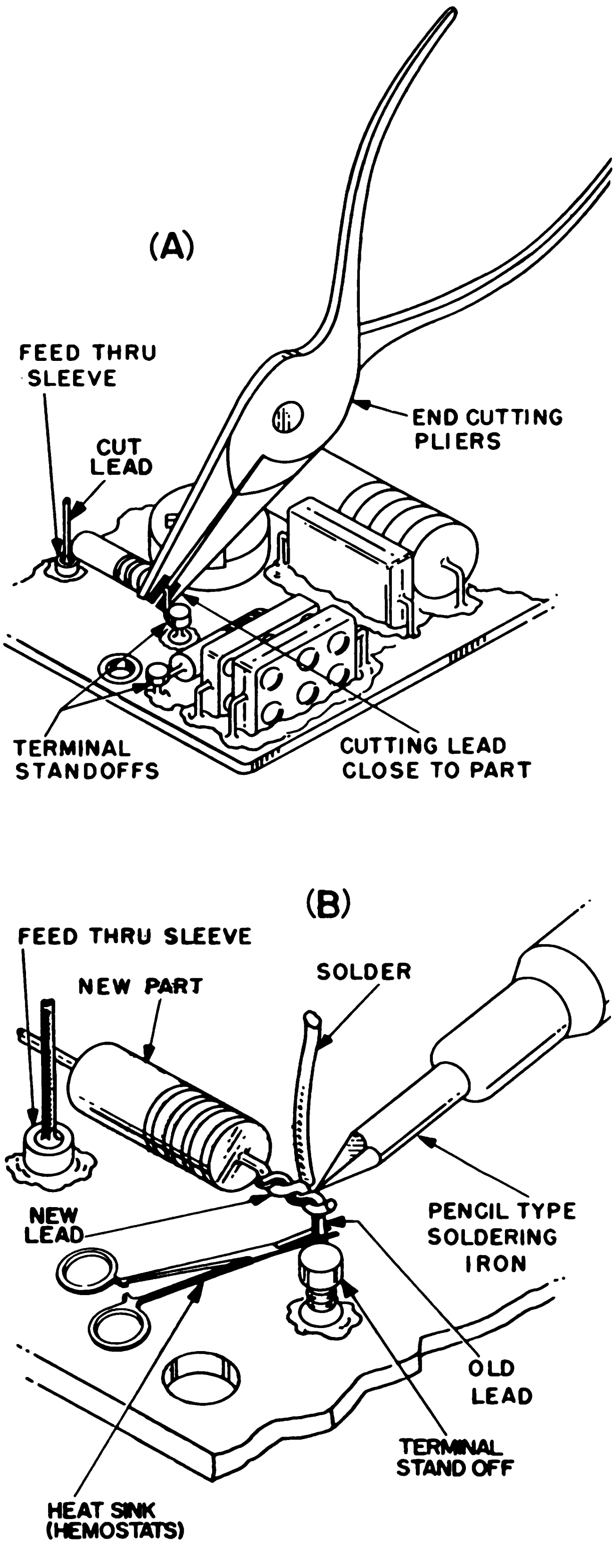


Figure 14-20.—Removing a defective part from a miniature standoff terminal.

ECCOBOND "55" epoxy adhesive, or its equivalent. A silver conductive paint or similar material can also be used to repair printed circuit conductive strips. This technique is satisfactory for temporary or emergency repair, but is not satisfactory for permanent repair.

A broken printed circuit board may have to be repaired in an emergency where no replacement is available. Before repairing the broken board, assess the damage for the extent of the break and the amount of damage to the parts involved. If the board is not too complicated or the damage too extensive, the board can probably be repaired.

If a small portion or corner of the board is broken off, it may be rebonded to the larger section with a nonconductive cement or its equivalent. If cementing is not feasible or does not hold satisfactorily, the pieces can be fastened together with wire staples cut from solid conducting wire of the diameter and length required, depending on the width of the conducting strip to be repaired.

To insert the staples, drill holes about 1/4 inch in from each side of the break (fig. 14-21). The holes should be just large enough to accommodate the wire used for stapling. (This may vary, depending on the width of the conductive strip to be repaired.) Drill the holes through the conducting strips so that the staples will provide a good electrical contact across the break; this method will permit the use of sufficient staples to hold the pieces together without danger to shorts between conductors. If the break is sufficiently large, position additional staples at all points possible to give the board more support.

Where the adhesive and stapling method described above does not provide structural strength or sufficient rigidity, splints or a doubler may be used. Strips of thin card material are glued across the fracture with a nonconductive adhesive. Where needed, additional strength may be obtained by gluing a plate of the card material to the splints with the nonconductive adhesive.

Rebond any loose conducting strips with a nonconductive bonding cement; then apply nonconductive cement to both sides of the break, and join the sections together (fig. 14-21 (B)). Insert half of the measured and precut wire staples from top to bottom, and the other half from bottom to top, bending the ends slush against the board (fig. 14-21 (E)). Solder these staples to the conducting strip (fig. 14-21 (D)).

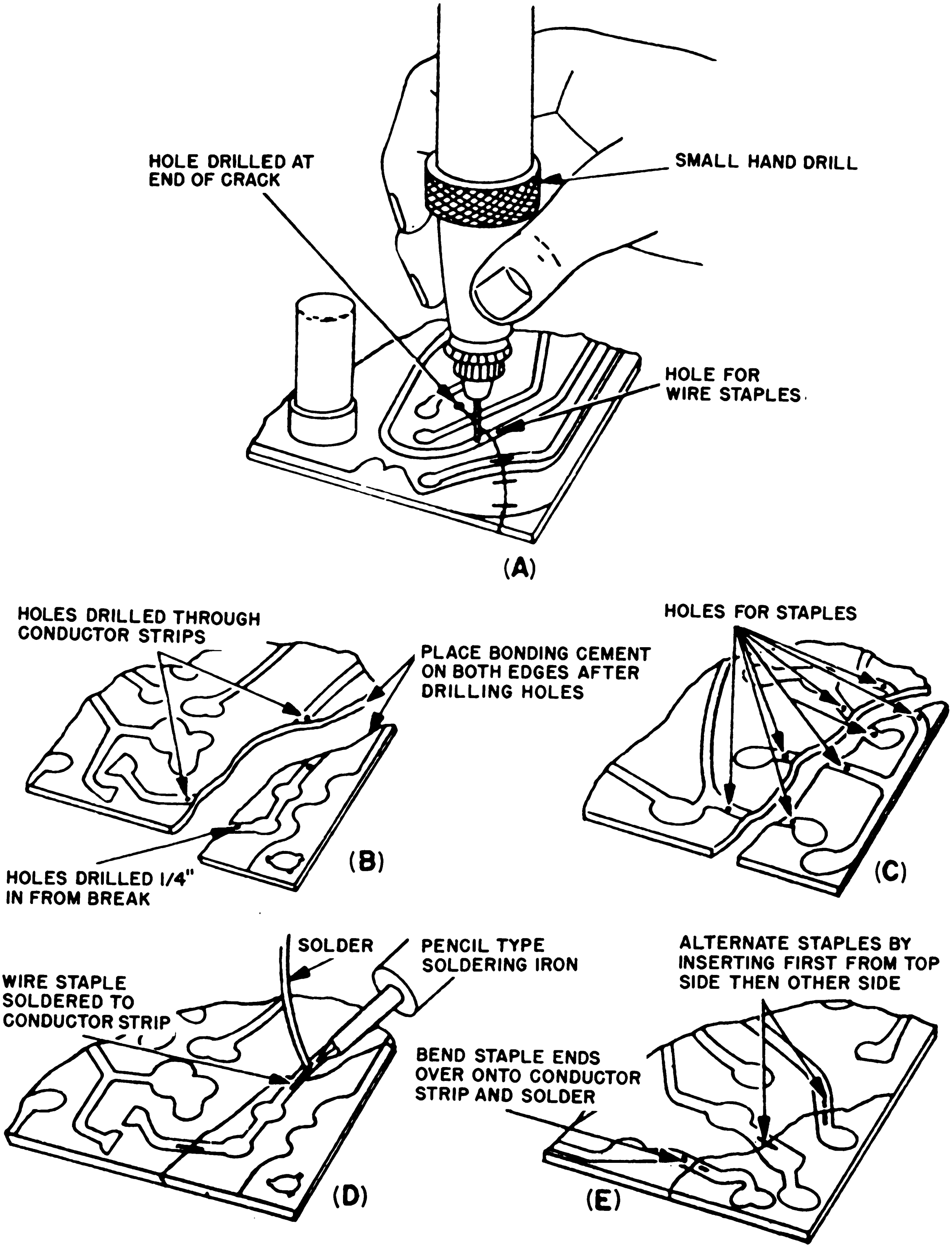


Figure 14-21.—Repairing a broken printed circuit board.

If the board is not completely broken but is only cracked, drill a hole at the end of each crack (fig. 14-21 (A)) to prevent further lengthening of the break. Then repair the crack in the same manner as the complete break discussed above.

After the repairs are completed, clean both sides of the repaired area with a stiff brush and solvent. Allow the board to dry thoroughly, then coat the repaired area with an epoxy resin or similar compound. This coating not only will protect the repaired area, but will help to strengthen it.

NOTE: The repair techniques given above are for emergency repair ONLY.

MODULES AND POTTED COMPONENTS

This section provides information so that an AE, using the techniques and procedures discussed in this chapter, can repair and restore modular constructed equipment quickly and efficiently.

The following established definitions will be helpful in understanding the terms involved. A module is defined as a unit or standard of measurement—a fixed dimension. A modular assembly has outline dimensions which are multiples of a module. Equipment which consists of replaceable assemblies (any type tubes, transistors, etc.) is said to be of unitized construction. Modular construction, then, is a type of unitized construction consisting predominately of modular assemblies.

The sketches in figure 14-22 show two possible arrangements of modular construction. Note that the blocks can be arranged in more than one way to approximately the same dimensions.

The original concept of many modular assemblies was that they should not be maintained in the field. The intention was to replace the assembly and ship it back to some repair facility. As assemblies became more complex, the point was soon reached where the extensive supply system required for the replacement concept was too costly. Many equipments built during this initial stage were potted with some secret ingredient to discourage maintenance personnel from tampering with the insides of a black box. When the Navy reassessed this concept, realizing that the fleet must maintain everything it could, most of the equipment manufacturers began to make components accessible. However, many technicians are still convinced that modular assemblies are impossible to repair. This conviction may stem from a lack of experience in working with the printed circuits and the other components in modular assemblies. While it is true that special tools and techniques are required, it is also true that satisfactory repairs can be made to any printed circuit by using just a little care and commonsense. Actually, with a little experience, repairs can be made as easily as in conventional assemblies—often more easily because of improved accessibility.

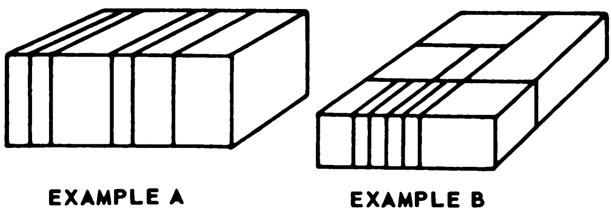


Figure 14-22.—Two examples of modular construction.

The techniques and procedures previously discussed concerning soldering techniques, transistors (and heat dissipators), printed circuits (and printed wire, etc.), removing and replacing components and/or parts, and special and emergency techniques are applicable to all modular constructed modular assemblies.

Potting of circuit boards is used because the operating time between repairs can be considerably increased by its use. The sealing of components prevents their exposure to moisture. The potting is first done by the manufacturer at the time of installation of the components. Portions of the components are potted together as a unit and are mounted on the circuit board (fig. 14-23).

Maintenance of potted components begins with the necessity of removing the potting compound. This problem should be minimized by the fact that most potted sections do not require repair. The manufacturer's maintenance manual should provide the decision whether or not to remove the potting. If the removal is necessary, the manual should contain illustrations and instructions of the sections to be repaired. The potting compound on some assemblies is easily removed because the assembly was enclosed in a plastic bag prior to potting. In this manner the assembly is potted but the compound is prevented from flowing around or adhering to the detail parts. Circuit boards which are potted in this manner can be cleared by cutting a parting line

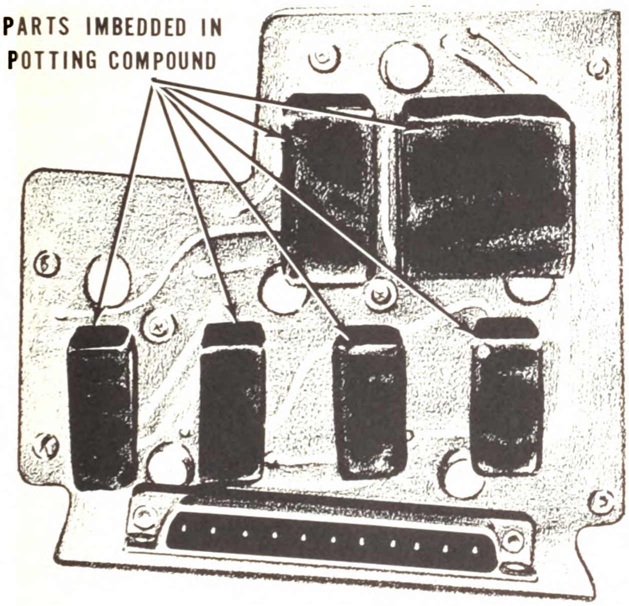


Figure 14-23.—Potting.

around the edge of the lamination and removing the two halves.

The repair of this type of assembly is the same as that required of all circuit board assemblies, except for the additional problems created by potted materials. After repair has been performed, the potting material must be restored in accordance with instructions contained in the manufacturer's maintenance manual.

SAFETY PRECAUTIONS

The only hazards involved in the maintenance of printed circuit boards are those that would be encountered in any electrical/instrument maintenance activity. However, the solvents and some of the materials used in the protective coating process require the following precautions:

1. Flamable liquids must be stored in approved containers and enclosures.
2. Some liquids are possible irritants and somewhat volatile. Do not allow liquids to come into contact with the skin. If it happens accidentally, wash the area immediately with soap and water. Use an apron and gloves.
3. Use solvents and coating materials under a hood or exhaust fan to avoid inhalation of fumes.

CORROSION CONTROL

A highly important phase of any inspection and preventive maintenance program is corrosion control. Corrosion is likely to occur on the components of electronic equipments, as well as the surfaces of larger structures such as equipment housings, etc. Of particular interest to the AE is the danger of corrosion on such vulnerable areas as the cables and reel assemblies of automatic flight equipment.

Electronic and electrical package compartments cooled by ram air or compressor bleed air are subjected to the same conditions common to engine and accessory cooling vents and engine frontal areas. Figure 14-24 shows points (indicated by arrows) where corrosion is likely to be found in air-cooled compartments. While the degree of exposure is less (because of a

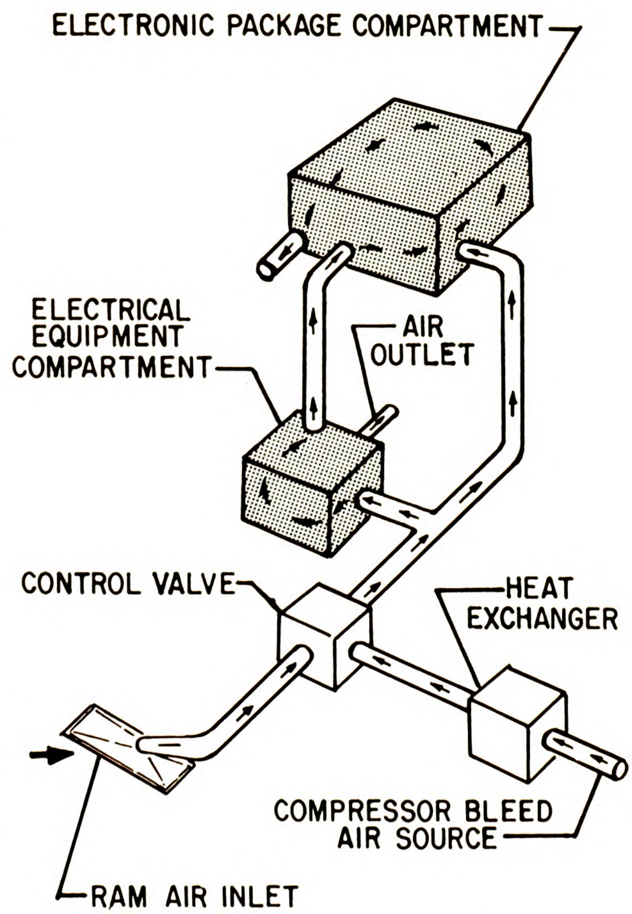


Figure 14-24.—Air-cooled compartment corrosion points.

lower volume of air passing through and special design features incorporated to prevent water formation in the enclosed spaces), this is still a trouble area that requires special attention.

Circuit breakers, contact points, and switches are extremely sensitive to moisture and corrosive attack and should be inspected for these conditions as thoroughly as design permits during routine checks. If design features hinder examination of these items while in the installed condition, advantage should be taken of component removals for other reasons, with careful inspection for corrosion required before reinstallation. Treatment of corrosion in electrical and electronic components should be done only by or under the direction of personnel familiar with the function of the unit involved, as conventional corrosion treatment may be detrimental to some units.

NATURE OF CORROSION

The word corrosion denotes the destruction of metals by chemical or electrochemical action. The corrosion process converts the metal into a metallic compound such as an oxide, hydroxide, or sulfate. The process always involves two simultaneous changes: The metal that is attacked or oxidized suffers what is called an anodic change, while the corrosive agent is reduced (deoxidized) and may be looked upon as undergoing a cathodic change.

Corrosion is generally of two types. One is direct chemical attack, wherein the anodic change occurs at the surface of the metal and the cathodic change takes place within the corrosive chemical—the action of acid on metal, for example. The other is an electrochemical attack, wherein the anodic and cathodic changes occur at the surfaces of two dissimilar metals.

This type of corrosion necessarily involves a conductive medium such as dirty water or salt water (through which electrically charged ions and electrons may pass) and mechanical contact or connection through a structure to close the circuit. A galvanic cell is thus formed, giving rise to the term "galvanic corrosion." Another term sometimes used is "bimetal corrosion."

Galvanic corrosion is a familiar occurrence wherever dissimilar metals are located close together in a structure. When such an area is wet with salt water, for example, the material undergoing anodic change begins to corrode. At the same time, material (usually hydrogen ions) is released in the area of the other metal.

Both types of corrosion normally depend on moisture to provide a conductive medium for ions and electrons. A truly dry material will not normally attack metal. Even moisture in the air, however, is often sufficient to start the action. If we could keep all metals enclosed in airtight bags with all moisture removed, we would probably never have a corrosion problem. All such attacks start on the surface of the metal where it is exposed to the corrosive environment. If allowed to progress, the corrosion works its way down into the core of the material. Since corrosion never originates in the core, there is evidence on the surface when the attack is in progress.

Aluminum and magnesium sheets, riveted together to form the skin of an aircraft wing, serve as an example of the galvanic couple. A second example may be observed when magnesium pieces are attached with steel bolts or screws in the presence of moisture; galvanic corrosion can occur between the magnesium and steel. During this process an electrical potential is established, and current flows between the two metals. The potential difference created between the metals depends on the relative chemical activity of the two metals. for example, magnesium in contact with copper will corrode faster than magnesium in contact with zinc because copper is less active than zinc; the potential difference created by the magnesium-copper combination is greater. This relationship is illustrated in table 14-3.

Table 14-3.—Abbreviated list of metals in order of decreasing activity in the galvanic series.

Group	Metal
I	Magnesium and its alloys
II	Zinc Aluminum and its alloys Cadmium
III	Steel and its alloys
IV	Brass Copper Stainless steel

Materials of any one group listed in table 14-3 will suffer galvanic attack when in contact with materials of any other group. The different metals within a group do not cause serious galvanic attacks when in contact.

PREVENTION OF CORROSION

One of the fundamental factors in corrosion prevention is the nature of the material itself. All high strength, heat-treatable aluminum alloys are susceptible to intergranular corrosion as well as pitting and general attack. All magnesium alloys are highly susceptible to general and pitting attack when exposed to a corrosive environment. Materials must be selected primarily on a basis of structural efficiency; corrosion resistance, of necessity, is at times a secondary consideration at the design level.

Use of more corrosion-resistant materials in a given design may involve a substantial amount of additional weight which is considered to be more serious than the cost of preventing corrosion by proper maintenance.

Another factor in the corrosion problem over which there is not practical method of control is the section size of the material. Thicker sections are normally more susceptible to corrosion than thinner sections because of the slower reaction of heavy masses during the quenching cycle of the heat-treating process. However, the section size is determined by the individual requirements for the part; the size cannot be changed or adapted for the purpose of controlling corrosion.

Heat treatment of the material is a vital factor in establishing its resistance to corrosion, and one over which a definite control can be exercised by the manufacturer. In order to insure properly treated parts, a rigid inspection is usually maintained by the manufacturer both of the heat-treating processes and of the facilities used. To insure that replacement parts meet the manufacturer's heat-treating specifications, it is essential that such parts be procured either directly from the manufacturer or from approved sources.

Another consideration is the effect of geographical location. The location in which the aircraft is operating will determine the amount of exposure to salt water, moisture condensation, temperature conditions, chemicals, soil, and dust in the atmosphere. Control of this factor is dependent on the need for operating at a specific location.

PROTECTIVE MEASURES

An effective program requires the earliest possible repair of damaged protective coatings, including the removal of corrosion products and the refinishing of corroded surfaces. It involves the maximum use of supplementary protective agents during any waiting periods or until such time as more positive protection can be restored. It must be a continuous program and recognized as everyone's responsibility.

Effective maintenance must vary with the operating schedule and be sufficiently flexible to meet any changing conditions that may be encountered. Such a program will pay high dividends in more efficient operation of equipment, in less downtime for corrective measures, and in safer operation generally.

Periods of neglect or touchup maintenance, which may be necessary under operating conditions, should be followed by a period of concentrated effort to correct any deficiencies which have started. A successful preventive maintenance program will tend to reduce the effects of severe service environments and the susceptibility of most aircraft materials to damage by them.

Anticorrosion Materials

Electronic equipments are usually sprayed during manufacture with a protective coating that seals out moisture, thus preventing corrosion and fungus growth. In repair of these equipments it is sometimes necessary to remove the protective coating by scraping or by the use of solvent cleaners.

In general, solvent cleaners used in aircraft should have a flashpoint of not less than 40.6° C (105° F) if explosion proofing of equipment and other special precautions are to be adhered to. Chlorinated solvents of all types meet the nonflammable requirements but are toxic, and safety precautions must be observed in their use. The use of carbon tetrachloride is specifically prohibited. Stoddard solvent (P-S 661B), Federal Stock Number W-6850-264-9038, flashes slightly above 40.6° C and can be used to remove greases, oils and light soils. Safety solvent, Trichloroethane (methyl chloroform), is used for general cleaning and grease removal. It is nonflammable under ordinary circumstances, and is used as a replacement for carbon tetrachloride. The use

and safety precautions necessary when using chlorinated solvents must be observed. Prolonged use can cause dermititis (skin irritation) in some persons.

After making circuit repairs, the protective coating should be replaced. Rosin fluxes form coatings on solder connections that prevent oxidation during and after the soldering process, thus providing one form of replacement. A good general rule is that materials used should be those covered and controlled by military specifications, preferably those authorized specifically for use on aircraft. Many materials used for less critical applications may not be inhibited against breakdown in storage or may lack the properties considered necessary for application to aircraft. Commercial and proprietary preparations may not have been checked under aeronautical conditions. Use nonspecification materials only in emergencies, or where specific instructions so direct.

Extensive resealing operations for entire assemblies, units, or groups are beyond the scope of this discussion. For further information, see Corrosion Control for Aircraft, NavWeps 01-1A-509, and Preservation of Naval Aircraft, NavWeps 15-01-500.

Fungus-Resistant Materials

Fungus susceptibility of materials has long been a serious problem, particularly with electric gear which may be subjected to extremes of humidity under tropical temperatures. While the fungus itself is objectionable since it generally "fouls" all types of equipment, its most serious effect is the increased possibility of shorting and arcing because of its moisture content.

The fungus problem has been further aggravated in the past decade by the increased use of a large number of organic materials in equipment used by the Navy. These materials vary in nature and size from large sheets of reinforced plastic for structural components to special dielectric substances used in complex electronic gear.

To aid the user of materials in determining the fungus-resistance characteristics of all currently available substances in common use for a wide variety of naval uses, three general categories may be set up.

These three categories are listed in the Bureau of Ships Journal, NavShips 250-200, dated April 1962, along with a detailed listing of applicable materials under each heading. The basic categories are as follow:

1. Grade I: Materials which are fungus resistant in all known grades and conditions. These materials are either poisonous to fungi or offer no nutrient to fungi.

2. Grade II: Materials which are fungus resistant in certain grades only. These are substances which can be compounded to give properties equivalent to those of grade I materials.

3. Grade III: Materials not normally resistant to fungi. These substances present substantial problems (either economic or technical) in protection against fungus attack.

CHAPTER 15

PRESSURIZATION AND CABIN TEMPERATURE CONTROL

Most current aircraft require cabin or cockpit air pressure and temperature control because of the extreme speeds and altitudes at which they operate. The reason for cabin pressurization is to maintain a pressure altitude level within the cabin during high altitude flight, which is equivalent to that at substantially lower altitudes.

The cabin air-conditioning and pressurization system supplies conditioned air for heating and cooling the cockpit and crew spaces. This air also provides cabin pressurization to maintain the pilot(s) and crewmembers in a safe, comfortable environment. In addition to cabin air conditioning, some aircraft equipment and equipment compartments require air conditioning to prevent heat buildup and consequent damage to the equipment.

The majority of the air-conditioning systems installed in modern aircraft utilize air turbine refrigerating units to supply cooled air. These are called air cycle systems. One late model aircraft, the E-2A (W2F-1), utilizes a compressed gas cooling system for cooling of electronic equipment and electronic compartments. The refrigerating unit is a Freon type, quite similar in operation to a common household refrigerator. Systems utilizing this refrigeration principle are called vapor cycle systems.

TERMS AND DEFINITIONS

The system which maintains cabin air temperatures to meet the requirements for pilot efficiency is the air-conditioning system. The sources of heat which make cabin air conditioning necessary are:

1. Ram-air temperature.
2. Engine heat.
3. Solar heat.
4. Electrical heat.
5. Body heat of personnel.

Ram air temperature is the frictional temperature increase created by ram compression on the skin surface of an aircraft. This factor becomes serious only at extreme airspeeds. For example, if an aircraft were flying at 45,000 feet, at a speed of 1,200 mph, the ram air temperature would be about 2000° F on some parts of the aircraft. This extreme temperature plus the heat from the other sources would cause the cockpit temperature to rise to about 190° F. The maximum temperature that a pilot can endure and still maintain top physical and mental efficiency is about 80° F. Prolonged exposure to a temperature greater than 80° F will seriously impair his mental and physical condition. Furthermore, under low-speed operating conditions at low temperature, cabin heating may be required.

It is necessary to become familiar with some terms and definitions, for understanding of the operating principles of pressurization and air-conditioning systems. NOTE: Some of the terms were discussed in chapter 3, Physics of Heat, Fluids, and Gases. Although they are briefly defined in this chapter, a review of chapter 3 should be beneficial. These are as follows:

1. Absolute pressure—Pressure measured along a scale which has zero value at a complete vacuum.
2. Absolute temperature—Temperature measured along a scale which has zero value at that point where there is no molecular motion (-273.1° C or -459.6° F).
3. Adiabatic—A word meaning no transfer of heat. The adiabatic process is one in which no heat is transferred between the working substance and any outside source.
4. Aircraft altitude—The actual height above sea level at which an aircraft is flying.
5. Ambient temperature—The temperature in the area immediately surrounding the object under discussion.

6. Ambient pressure—The pressure in the area immediately surrounding the object under discussion.

7. Standard barometric pressure—The weight of gases in the atmosphere sufficient to hold up a column of mercury 760 millimeters high (approximately 30 inches) at sea level (14.7 psi). This pressure decreases with altitude, in a logarithmic manner.

8. Cockpit altitude—Used to express cockpit pressure in terms of equivalent altitude above sea level.

9. Differential pressure—The difference in pressure between the pressure acting on one side of a wall and the pressure acting on the other side of the wall. In aircraft air-conditioning and pressurizing systems, it is the difference between cabin pressure and atmospheric pressure.

10. Gage pressure—A measure of the pressure in a vessel, container, or line, as compared to ambient pressure.

11. Ram-air temperature rise—The increase in temperature created by the ram compression on the surface of an aircraft traveling at a high rate of speed through the atmosphere. The rate of increase is proportional to the square of the speed of the object.

12. Temperature scales:

a. Centigrade—A scale on which 0° C represents the freezing point of water and 100° C is equivalent to the boiling point of water at sea level.

b. Fahrenheit—A scale on which 32° F represents the freezing point of water and 212° F is equivalent to the boiling point of water at sea level.

There are five basic requirements for cabin pressurizing and air-conditioning systems:

1. A pressurized area of the aircraft, usually the cockpit or cabin, designed to withstand the specified pressure differential.
2. An adequate source of compressed air.
3. A means of controlling the cabin pressure by regulating the outflow of air from the cabin.
4. A means of dumping all regulated air from the cabin, and provisions for obtaining fresh air.
5. A means of conditioning (in most cases cooling) the compressed air before it enters the cabin.

The design of the cabin, to withstand the pressure differential and hold leakage of air within the limits of the pressurization system, is primarily an airframe engineering and manufacturing problem. An adequate air supply, is provided by a separate air compressor or air from the compressor section of the aircraft's jet engine. Control of the outflow of air from the cabin is provided by the cabin pressure regulator. Rapid expulsion of air that may be contaminated is accomplished through the cabin dump valve. This is operated by an electrical switch. Simultaneously, fresh ram air may be brought into the cabin through the ambient air shutoff valve. A means of conditioning (cooling) air, is provided by an aircraft refrigerator unit.

In addition to the components just discussed, various valves, controls, and allied units are necessary to complete a cabin pressurizing and air-conditioning system. When auxiliary systems such as windshield anti-icing, canopy defrosting, pressurized canopy sealing, pressurized fuel tanks, and pressurized hydraulic tanks are required, additional shutoff valves and control units are necessary.

Figure 15-1 shows a schematic diagram of a pressurization and air-conditioning system. The exact details of this system are peculiar to only one model of aircraft, but the general concept is similar to that found in the majority of naval aircraft.

PRESSURE AND HEAT SOURCE

Hot, high-pressure air comes from a compressor, such as a supercharger, or the compressor section of a jet engine. The temperature of the bleed air delivered to the pressurizing and air-conditioning system is 300° to 800° F. The pressure of this air is from 75 to 250 psi.

The temperature of this air being delivered to the cockpit must be reduced to the point where the pilot's efficiency is not impaired. Normally, this is from 60° F to 80° F, depending on the pilot himself. In addition to reducing the temperature, the pressure of the air is also reduced. Atmospheric pressure at sea level is approximately 14.7 psi. Cockpit pressure is maintained as near as is practical to sea level pressure. As altitude increases, the atmospheric pressure decreases; current aircraft sometimes travel at altitudes where the atmospheric pressure is only 1 psi.

If an unprotected pilot were exposed to this near-vacuum air pressure, he would be seriously injured or killed. It is mandatory that all aircraft having an operating altitude of 35,000 feet or greater be equipped with pressurizing equipment.

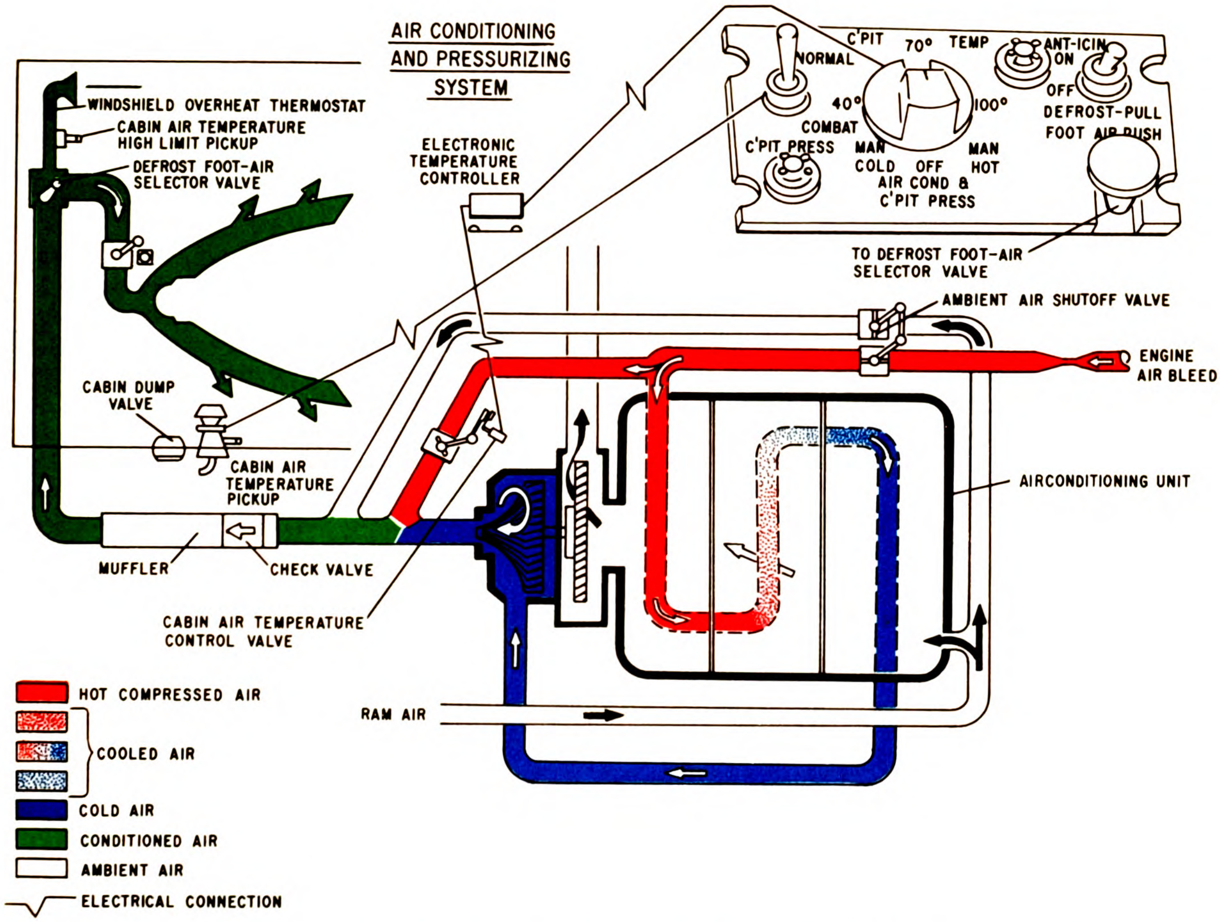


Figure 15-1.—Cockpit pressuring and air-conditioning system (schematic diagram).

PRIMARY HEAT EXCHANGER

The primary heat exchanger (located in the air-conditioning unit) is the first stage of cooling for the hot air coming from the compressor. (See fig. 15-1.) It is located downstream from the compressor and is similar to an automobile radiator. The hot air travels through metal cores in the same manner as water travels through an automobile radiator core. Cold ram air passes over the primary heat exchanger core in much the same manner as air is pulled through the automobile radiator by the fan; this is called air-to-air cooling. The flow of the cold ram air is routed by the ambient air shutoff valve. With the valve in the closed position, the cold ram air is directed through the primary heat exchanger; this allows maximum cooling of the hot air passing through the primary heat exchanger core.

With the ambient air shutoff valve open, there is no air-to-air cooling, because the ram air will bypass the heat exchanger and be routed directly to the cabin. Note that the engine air bleed valve is geared to the ambient air shutoff valve so that when the ambient air shutoff valve is open the bleed air valve is closed.

The position of the mixing valve (cabin air temperature control valve) is controlled by a d-c, split-field, electric motor; this motor is controlled either manually or automatically. In the manual mode, the pilot has direct control of the mixing valve through the temperature control switch.

In the automatic mode, the mixing valve is controlled by a bridge and amplifier circuit.

This automatic system has control of the mixing valve when the cockpit air temperature switch is placed in any position from 40° to 100° F.

In some installations where the air coming from the primary heat exchanger has not been cooled sufficiently, a second heat exchanger may be required to increase the efficiency of refrigeration. Units of this kind are called secondary heat exchangers.

SECONDARY HEAT EXCHANGER

The secondary heat exchanger is the next stage for cooling the warm air that leaves the primary heat exchanger. Figure 15-2 shows an aircraft refrigeration unit. This unit is a typical secondary heat exchanger.

Some installations use more than one secondary heat exchanger. These secondary exchangers operate on the principle of air-to-air cooling. The final stage of cooling will always employ the adiabatic process. The adiabatic process of operation is one in which no heat is transferred to or from a working substance. That is, the final cooling of cabin air is accomplished by means of rapid expansion, rather than exchange of heat.

The warm air from the primary heat exchanger enters the cabin air inlet (fig. 15-2). The inlet air passes through metal cores just as it did in the primary heat exchanger. At the same time, cooling air flows over the metal cores and again cools the cabin air by the air-to-air process. As the cooled cabin air leaves the cores, it is routed into an expansion turbine section. The cooling turbine utilizes the principle of cooling-by-expansion; rapid expansion causes cool air to become still cooler. The cooling-air discharge impeller, driven by the expansion turbine, boosts the flow of cooling air through the heat exchanger, thus increasing the efficiency of the refrigeration unit.

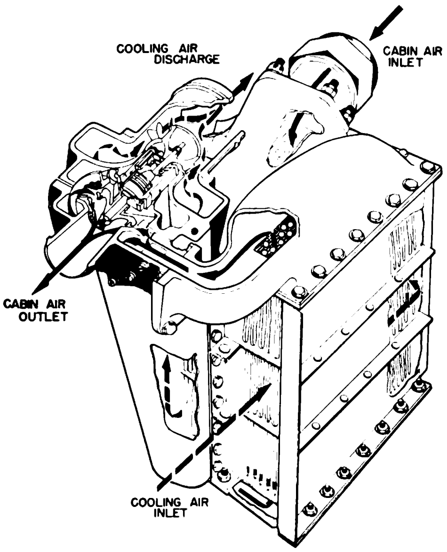


Figure 15-2.—Typical aircraft refrigeration unit.

The Aviation Structural Mechanic is responsible for the maintenance and installation of heat exchangers, turbines, ducting, and various mechanical valves. The Aviation Electrician is required to troubleshoot and maintain the electrical controlling features of the pressuring and air-conditioning system; however, the importance of the AE and AME working together cannot be overstressed.

MIXING VALVE

The mixing valve is enclosed in an aluminum alloy housing and is actuated by an electric motor. This valve is a modulating type and serves as a means of proportioning the hot engine-bleed air to the refrigerated air from the heat exchanger (fig. 15-1). Its operation depends on a butterfly valve connected to the motor by a mechanical gear assembly (fig. 15-3).

The motor that actuates the mixing valve is a split-field, d-c type motor, equipped with a magnetic brake. Contacts inside the motor housing break the circuit to the individual fields when the actuator is either in the fully opened or fully closed position. The reason for this is to prevent overloading of the motor.

The mixing valve is operated according to the demands of the cabin temperature control unit, to keep the temperature of the air delivered to the cabin within specified limits.

In some installations, the mixing valve may be identified by other names; for example, cabin air temperature control valve, bypass valve, modulating valve, or proportioning valve. All of these perform the same function and operate on the same principle.

ELECTRONIC CABIN TEMPERATURE CONTROL SYSTEM

The operation of the electronic temperature control system is based primarily on the

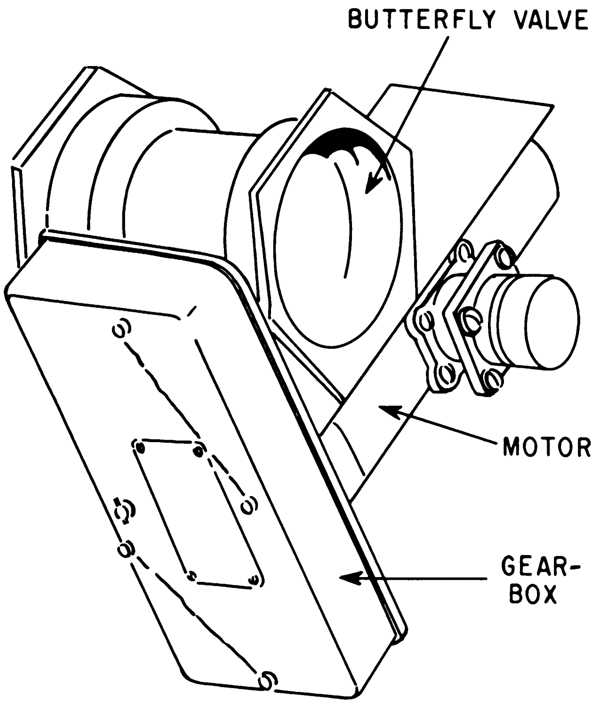


Figure 15-3.—Mixing valve.

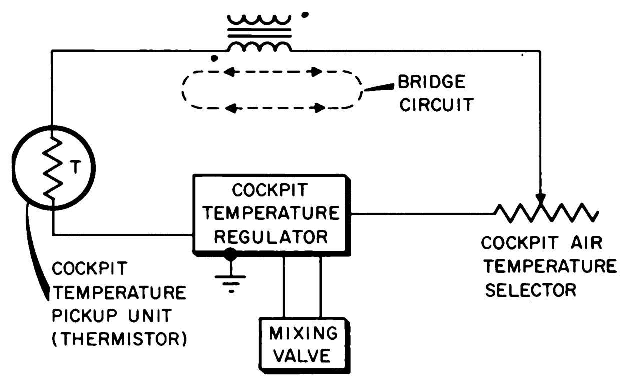


Figure 15-4.—Electronic air temperature control system (simplified).

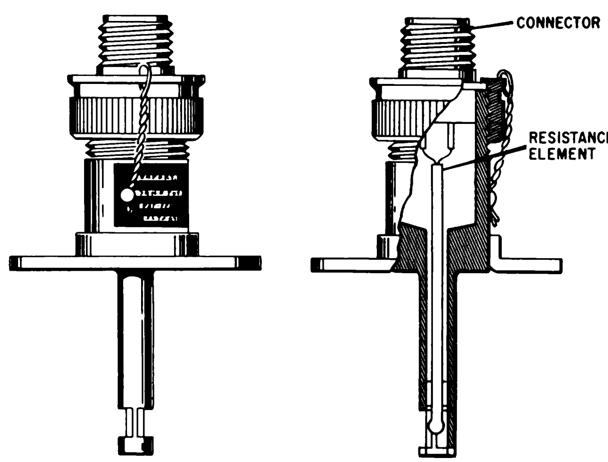


Figure 15-5.—Caging pickup.

balanced bridge circuit principle. When any of the units which compose the "legs" of the bridge circuit changes resistance value due to a temperature change, the bridge circuit becomes unbalanced. An electronic regulator receives an electrical signal as a result of this unbalance and amplifies this signal to control the mixing valve actuator.

In a typical application of the electronic temperature control system, three units are utilized. They are:

1. The electronic regulator.
2. The manual temperature selector.
3. The cockpit temperature pickup (thermistor).

Figure 15-4 shows a simplified schematic diagram of an electronic temperature control system.

COCKPIT TEMPERATURE PICKUP UNIT

The cockpit-temperature pickup unit (temperature sensing unit) consists of a resistor that is highly sensitive to temperature changes. The cockpit temperature pickup unit (fig. 15-5) is usually located in the cockpit or cockpit air supply duct. As the temperature of the air supply changes, the resistance value of the pickup unit also changes, thus causing the voltage drop across the pickup to change. The cockpit temperature pickup is a thermistor type unit. As the ambient temperature of the resistance bulb increases, the resistance of the bulb decreases. This is shown in the graph in figure 15-6.

COCKPIT AIR TEMPERATURE SELECTOR

The air temperature selector (fig. 15-4) is a rheostat located in the cockpit and is controlled by the pilot. It permits selective temperature control by varying the effective temperature control point of the cockpit air temperature pickup unit. The rheostat causes the

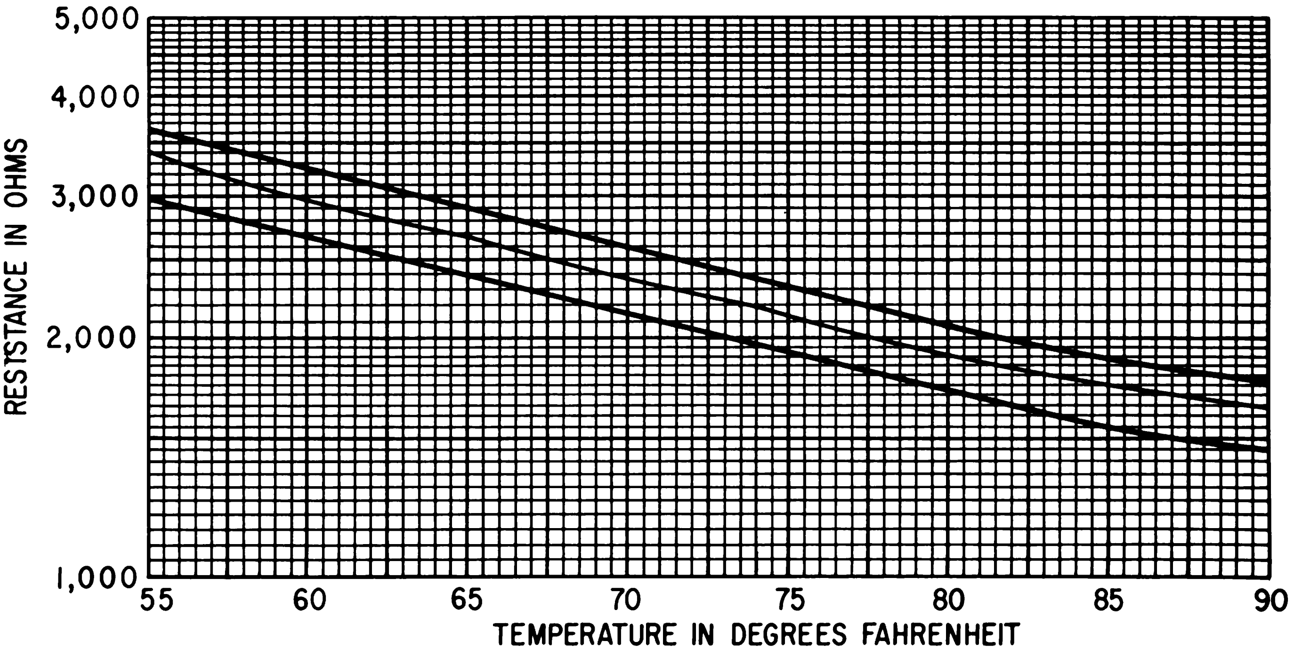


Figure 15-6.—Resistance-temperature graph.

cockpit temperature pickup unit to demand a specific temperature of the supply air.

COCKPIT AIR TEMPERATURE CONTROL REGULATOR

The cockpit air temperature control regulator, in conjunction with the cockpit air temperature selector rheostat and the cockpit air duct temperature pickup unit, automatically maintains the temperature of the air entering the cockpit at a preselected value. The cockpit temperature regulator is an electronic device with a temperature regulating range. In some installations, this range may extend from as low as 32° F to as high as 117° F.

The output of the regulator controls the position of the butterfly in the mixing valve, thus controlling the temperature of the inlet air to the cockpit.

TYPICAL SYSTEM OPERATION

Figure 15-7 shows an electrical schematic of a typical air temperature control system.

In most air temperature control systems, there is one switch located in the cockpit to select the mode of temperature control. Usually, this switch (cockpit air temperature control switch) will have four positions—OFF, AUTO (40° -70° -100°), MAN HOT, and MAN COLD. In the OFF position, the air temperature control system is inoperative. With the switch in the 40° -70° -100° range, the air temperature control system is in the automatic mode. With the switch in either the MAN HOT or MAN COLD position, the air temperature control system is in the manual mode.

1. OFF position—With the cockpit air temperature switch in the OFF position, the pilot has no control of the cockpit air temperature. The cockpit air temperature may become very cold, because the ambient air valve is open and the engine bleed valve closed.

2. MANUAL position—In the manual mode, the pilot can change the position of the butterfly valve by selecting MAN HOT or MAN COLD. This sends direct current to the hot-field or cold-field winding of the actuator. When the pilot uses this mode, he should return the control switch to the automatic range after the valve has traveled to a position at which the system is delivering the desired rapid change of temperature. Long periods of rapid temperature change are not usually needed.

3. AUTOMATIC position—In the automatic mode, the control switch is in a position

between 40° and 100°. This allows the direct current to be controlled by the regulator.

ELECTRONIC TEMPERATURE CONTROL REGULATOR

The cockpit selector rheostat and the cockpit air pickup unit (thermistor) determine the direction and amount of rotation of the mixing valve motor. This function is controlled in the cabin air temperature regulator. The cockpit selector rheostat and the cockpit air pickup unit (fig. 15-7) are connected into a bridge circuit which also includes two thermistors that are located in the regulator.

The bridge circuit is energized by an a-c source (T1). If the resistance of the cockpit air pickup unit and the cockpit selector rheostat were equal, then points A and B would have no potential difference.

Note that points A and B are the signal reference points for V1 (grid and cathode). If the cockpit air temperature increases, the resistance value of the cockpit air temperature pickup unit decreases, since the flow of the air passes over the pickup unit. This decrease in resistance of the pickup unit causes the voltage developed across the pickup unit to decrease, resulting in a potential difference between points A and B.

This signal, which is impressed on the grid of V1, goes through two stages of voltage amplification (V1 and V2). The amplified signal is applied to the grids of the two thyratron tubes (V3 and V4). The thyratron tubes are used for signal phase detection. For example, if the signal on the grid of V3 is in phase with the signal on the plate, V3 will conduct, causing current to flow through the coil of relay K1 and close its contacts.

One set of contacts completes a circuit for direct current flow to the cold-field coil of the mixing valve motor. This directs more hot air into the refrigeration outlet duct, thereby cooling the cockpit air.

At the same time, the remaining set of contacts of K1 completes a source of a-c power (T3) to the heating element of thermistor No. 1 of the bridge circuit, causing the resistance of thermistor No. 1 to decrease. (Remember that a thermistor's resistance decreases as the temperature rises.) The resultant change in the voltage drop across thermistor No. 1 results in a balanced bridge across points A and B. This, in turn, causes relay K1 to become deenergized, stopping the rotation of the mixing valve motor.

At this point, heater voltage is removed from thermistor No. 1 and it cools, again unbalancing the bridge. This causes the mixing

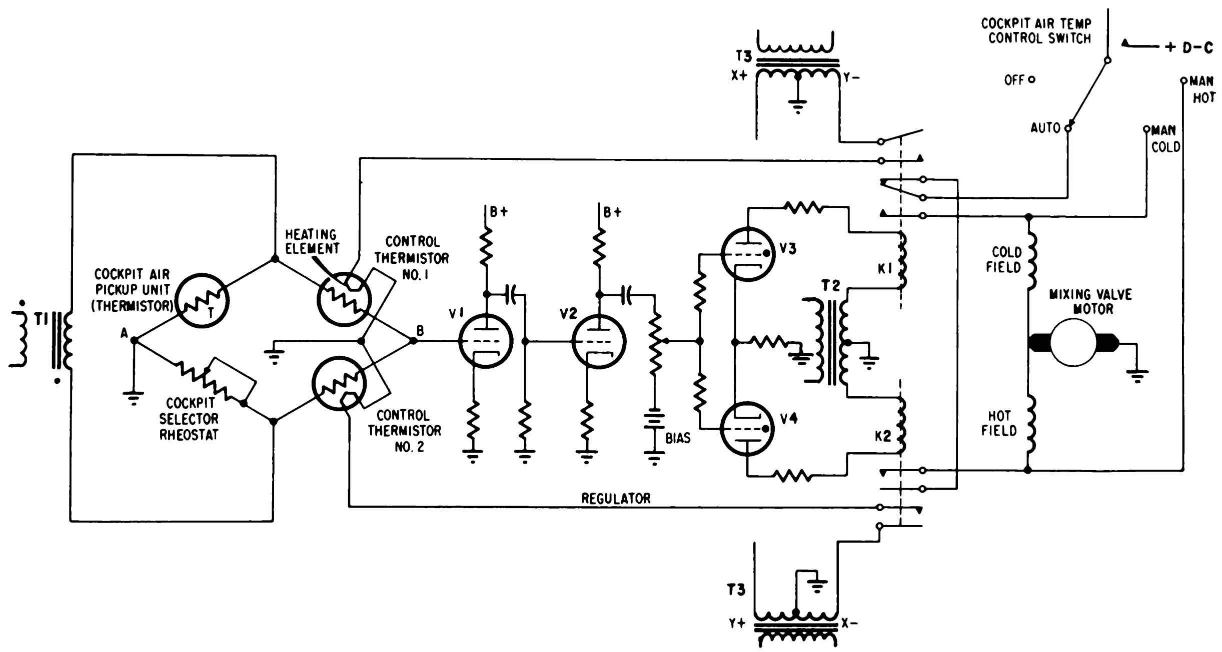


Figure 15-7.—Air temperature control system (simplified).

valve motor to drive farther towards the cool position, allowing still more refrigerated air to enter the cabin. Cycling continues until the drops in voltage across the cockpit pickup unit and the cockpit selector rheostat are equal.

Had the cabin air temperature been colder than the selected setting, the bridge would have become unbalanced in the opposite direction. This would have caused relay K2 in the regulator to become energized, thus energizing the hot-field coil of the mixing valve motor.

The bridge may also be unbalanced by another method. This is accomplished by repositioning the cockpit selector rheostat. Again the mixing valve moves to regulate the temperature of the air until the bridge is rebalanced.

COCKPIT PRESSURIZING SYSTEM

The cockpit pressurizing system provides control of the pressurized air which is supplied to the cockpit by means of the air-conditioning system ducts. This air is from the engine compressor section. A cockpit air pressure regulator maintains either of two manually selected cockpit air pressure schedules. These are referred to as combat schedule or normal schedule.

The first of these schedules (combat) consists of a nonpressurized cockpit from sea level to 10,000 feet and a constant 10,000-foot cockpit altitude pressure from an aircraft altitude of 10,000 feet to 18,000 feet. The combat schedule also maintains a 2.75 psi cockpit differential at all altitudes above 18,000 feet.

The alternate schedule (normal) consists of a nonpressurized cockpit from sea level to 10,000 feet and a constant 10,000-foot cockpit altitude from an aircraft altitude of 10,000 feet to 26,500 feet.

The cabin pressure regulator employs a solenoid valve. When the solenoid is energized with 27 volts d.c., it positions a metering valve and provides an alternate air pressure schedule of 5 psi differential pressure. With the solenoid deenergized, the metering valve provides an air pressure schedule of 2.75 psi differential.

On some naval aircraft cockpit pressurization is automatically initiated at 8,000 feet; the cockpit pressure is maintained at 8,000 until a pressure differential of 5 psi is reached. The cockpit is maintained at this pressure by the cabin pressure regulator as the aircraft climbs until a cockpit-to-ambient pressure differential of 5 psi is reached. Beyond this altitude, the valve regulates the exhaust flow to maintain this constant pressure differential throughout the remaining altitude range.

ADDITIONAL VALVES

If the cockpit air becomes contaminated or the pressurization system fails, the temperature-control switch should be turned to the OFF position. This will open a valve to admit ambient air, thus depressurizing the cockpit and clearing it of contaminated air; it will also close the engine air shutoff valve. Refer to figure 15-1 for the location of these valves in a typical pressurizing and heating system.

The shutoff valves should be checked for binding of the butterfly (or gate) and for linkage which is loose, bent, binding, or broken. All valves should be checked for security of mounting and for loose connections. Any appreciable leakage through a shutoff valve is an indication that the valve should be investigated. The travel limits of any valve should be checked at the first sign of malfunctioning, by observation of the butterfly position when the cockpit control is in the OFF position and in the ON position.

EQUIPMENT COOLING

Various avionics packages aboard some current naval aircraft generate heat in quantities that would be detrimental to their operation if cooling facilities were not incorporated.

AIR CYCLE SYSTEM

One method of cooling is accomplished by the air cycle system (discussed earlier in this chapter). The same air supply used for cabin air-conditioning is ducted through appropriate valves to various electronic compartments and avionics equipment.

VAPOR CYCLE SYSTEM

Another cooling system utilized for avionics equipment is the vapor cycle system, such as employed on the E-2 Hawkeye aircraft. A typical vapor cycle system flow schematic is shown in figure 15-8.

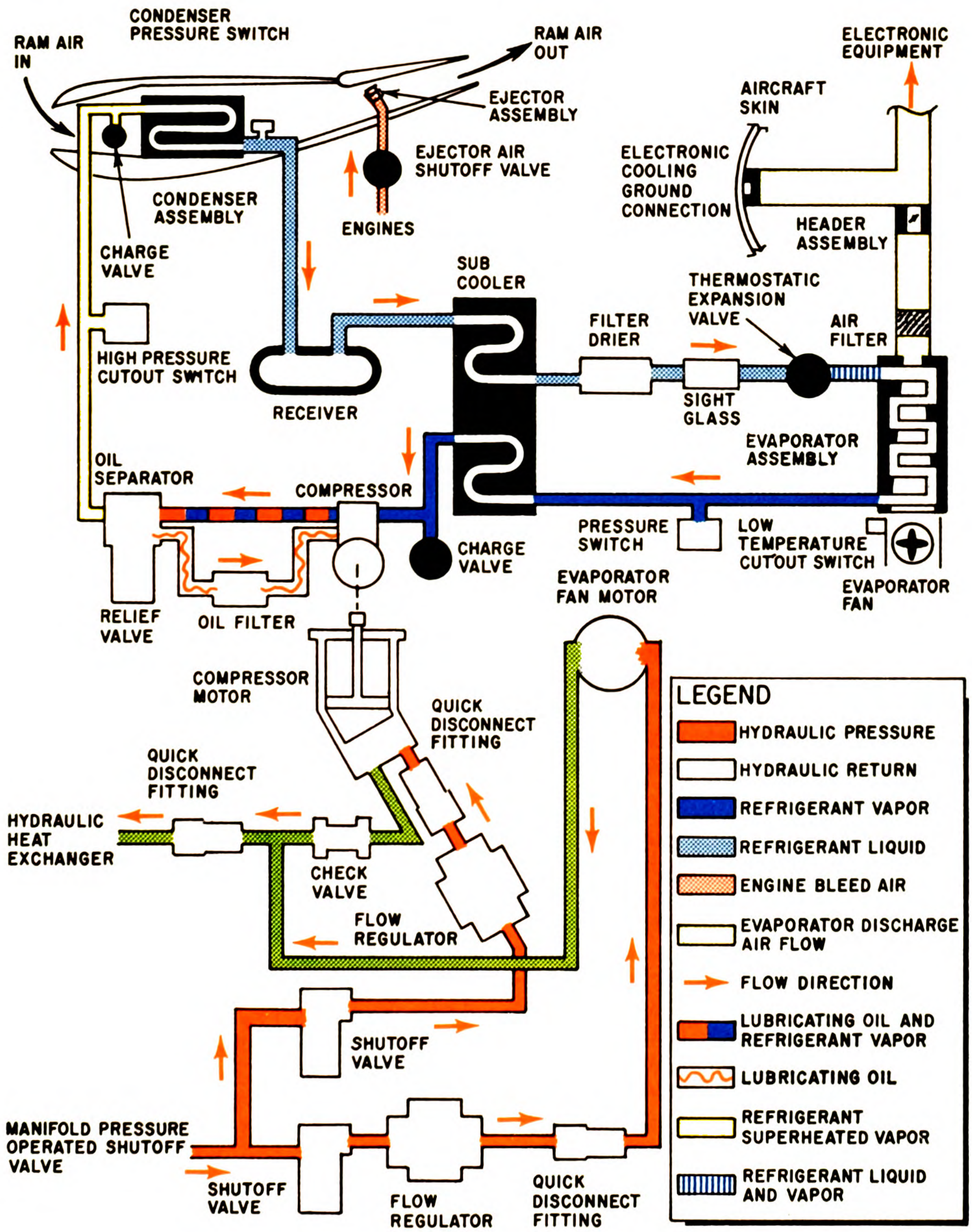


Figure 15-8.—Vapor cycle system flow schematic.

Vapor cycle systems make use of the scientific fact that a liquid can be vaporized at any temperature by changing the pressure above it. Water, at sea level barometric pressure of 14.7 psi, will boil if its temperature is raised to 212°F. The same water in a closed tank under a pressure of 90 psia will not boil at less than 320°F. If the pressure was reduced to 0.95 psia by a vacuum pump the water would boil at 100°F. If the pressure was reduced further the water

would boil at a still lower temperature; for instance, at 0.12 psia, boiling of water would occur at 40°F. Water can be made to boil at any temperature if the pressure corresponding to the desired boiling temperature can be maintained.

Liquids that will boil at low temperatures are the most desirable for use as refrigerants. Comparatively large quantities of heat are absorbed when liquids are evaporated, that is, changed to a vapor. For this reason, liquid Freon 12 is used in most vapor cycle refrigeration units whether used in aircraft or in home air conditioners and refrigerators.

If liquid Freon 12 was poured into an open container surrounded by standard sea level pressure, it would boil at temperatures above -22°F. There would be a continuous flow of heat from the warm surrounding air through the walls of the container to the boiling Freon. Moisture from the air would condense and freeze on the exterior of the container.

This system would work satisfactorily insofar as cooling alone is concerned. A drum of Freon could be connected to a coil and the vaporized Freon piped outdoors. An installation such as this would provide satisfactory refrigeration, but the cost of replacing the refrigerant would be prohibitive. Because of the cost involved, it is desirable to reuse the refrigerant. To accomplish this, additional equipment is required.

The refrigerant must be delivered to the evaporator as a liquid if it is to absorb large quantities of heat. Since it leaves the evaporator in the form of a vapor, some way of condensing the vapor is necessary. To condense the refrigerant vapor, the heat surrendered by the vapor during condensation must be transferred to some other medium. For this purpose, water or air is ordinarily the medium used. (Air is always used in aircraft systems.) The medium must be at a temperature lower than the condensing temperature of the refrigerant. At any given pressure the condensing and vaporizing temperatures of a fluid are the same.

If a refrigerant which vaporizes at 40° F is to be condensed at the same temperature, a cooling medium at a lower temperature is needed. Obviously, if a lower temperature medium were available, mechanical refrigeration would not be required. As the temperature of the available medium is usually higher than the temperature of the boiling refrigerant in the evaporator, the refrigerant cannot be condensed as it leaves the evaporator. In order to condense the vapor, its pressure must be increased to such a point that its condensing temperature will be above the temperature of the medium available. After the pressure of the refrigerant vapor has been increased sufficiently (using a compressor), it may be liquified in the condenser at a comparatively warm temperature. The only reason that the compressor and condenser are introduced into the system is to enable the refrigerant to be reused.

In a practical refrigeration circuit, liquid flows from the receiver to the expansion valve which is essentially nothing more than a needle valve. The compressor maintains a difference in pressure between the evaporator and the condenser. Without the expansion valve, this difference in pressure could not be maintained. The expansion valve separates the high pressure part of the system from the low pressure part. It acts as a pressure reducing valve because the pressure of the liquid flowing through it is lowered. Only a small trickle of refrigerant fluid flows through the valve into the evaporator. The valve is always so adjusted that only just as much liquid can pass through it as can be vaporized in the evaporator.

The liquid that flows through the evaporator is entirely vaporized by the heat flowing through the walls of the evaporator. This heat has been removed from the air being cooled.

After leaving the evaporator, the vaporized refrigerant flows to the compressor and is compressed to a point where it can be condensed. After being compressed, the vapor flows to the condenser. Here, the walls of the condenser are cooled by the medium, and, as a result, the vapor is liquified. Heat is transferred from the condensing vapor through the walls of the condenser to the medium. From the condenser the liquid refrigerant flows back to the receiver, and the cycle is then repeated.

The quantity of heat that each pound of refrigerant liquid absorbs while flowing through the evaporator is known as the refrigeration effect. Each pound flowing through the evaporator is able to absorb only the heat needed to vaporize it, if no superheating takes place. If the liquid approaching the expansion valve was at exactly the temperature at which it was vaporizing in the evaporator, the quantity of heat that the refrigerant could absorb would be equal to its latent heat.

When liquid refrigerant is admitted to the evaporator, it is completely vaporized before it

reaches the outlet. Since the liquid is vaporized at a low temperature, the vapor is still cold after the liquid has completely evaporated. As the cold vapor flows through the balance of the evaporator, it continues to absorb heat and becomes superheated.

The vapor absorbs sensible heat in the evaporater as it becomes superheated. This, in effect, increases the refrigerating effect of each pound of refrigerant. This means that each pound of refrigerant absorbs not only the heat required to vaporize it, but also an additional amount of sensible heat which superheats it.

Subcooling is a term used to describe the cooling of a liquid refrigerant at constant pressure to a point below the temperature at which it was condensed. At 117 psig, Freon 12 vapor condenses at a temperature of 100°F. If, after the vapor has been completely condensed, the liquid is cooled still further to a temperature of 76°F, it will have been subcooled 24°. Through subcooling, the liquid delivered to the expansion valve is cool enough to prevent most of the flash gas (premature vaporization) that would normally result, thereby making the system more efficient.

THEORY OF OPERATION OF A TYPICAL AIRCRAFT SYSTEM

When the equip cool switch ((1) fig.15-9) is set to ON, 28 volts d.c. is applied from the left transformer-rectifier bus through the left tr bus (2) and the d-c equip cool circuit breaker (3) to the evaporator fan motor solenoid valve (4). (NOTE: In studying the operation of the vapor cycle system, the AE should study both fig. 15-8 and fig. 15-9.) When energized, the solenoid valve opens to permit 3,000 psi hydraulic pressure to operate the evaporator fan motor. The 28 volts d.c. also energizes the compressor power relay (5) through the cutout relay (6) contacts and the low temperature cutout switch (7). When energized, the compressor power relay applies 28 volts d.c. to open the normally closed compressor motor solenoid valve (8), which then permits 3,000 psi hydraulic pressure to operate the compressor motor.

The compressor motor circuit is interconnected with the left and right engine indicator relays (9) (energized by the auto feather circuits), the landing gear handle position indicator relays (10), and the left and right wheel uplock switches (11). When either engine is in auto feather and the landing gear is down, the relays open a circuit to deenergize the compressor power relay, close the compressor motor solenoid valve, and deenergizes the compressor motor. The evaporator fan motor continues to operate.

With the equip cool switch set to ON(1), 115 volts a.c. is supplied from the right generator bus through the right gen bus ØB (12) and the a-c equip cool circuit breaker (13) to the condenser pressure switch (14). This switch controls the condenser door actuator (15) by permitting the 115 volts a.c. to energize the actuator to either extend or retract, depending upon refrigerant pressures in the condenser assembly. The actuator controls ram airflow through the vapor cycle scoop by varying the position of the flap door at the scoop's outlet.

With the evaporator-fan and compressor motors operating, low-pressure, low-temperature, Freon-12 vapor enters the compressor assembly through the low pressure line leading from the evaporator assembly outlet. (See fig. 15-8.) The vapor entering the compressor inlet combines with lubricating oil that is fed to the compressor motor. The oil-refrigerant mixture is compressed to raise its condensing temperature. From the compressor assembly, the high temperature, high pressure, mixture flows to the oil separator, where the oil is removed from the refrigerant vapor. The oil is filtered and fed back to the compressor motor.

If the pressure in the line downstream from the oil separator exceeds 305 psia, the high pressure cutout switch (16) applies 28 volts d.c. to energize the cutout relay (6), which permits 28 volts d.c. to light the equip cool caution light (17). The relay also opens the circuit to the compressor motor solenoid valve to shut off hydraulic power to the compressor motor and deenergizes the compressor. If the cutout switch (16) malfunctions, the pressure relief valve in the compressor discharge line relieves the system of excess pressure. Refrigerant vapor from the oil separator enters the condenser assembly, where cool ram air lowers its temperature and changes the vapor to a liquid.

At the outlet of the condenser assembly, the condenser pressure switch (14) senses the pressure of the liquid refrigerant and maintains the pressure within 72 to 88 psig. If refrigerant pressure exceeds 88 psig, the condenser pressure switch permits 115 volts a.c. to energize the condenser door actuator (15) to extend. As the actuator extends, it opens the flap door at the vapor cycle scoop outlet,

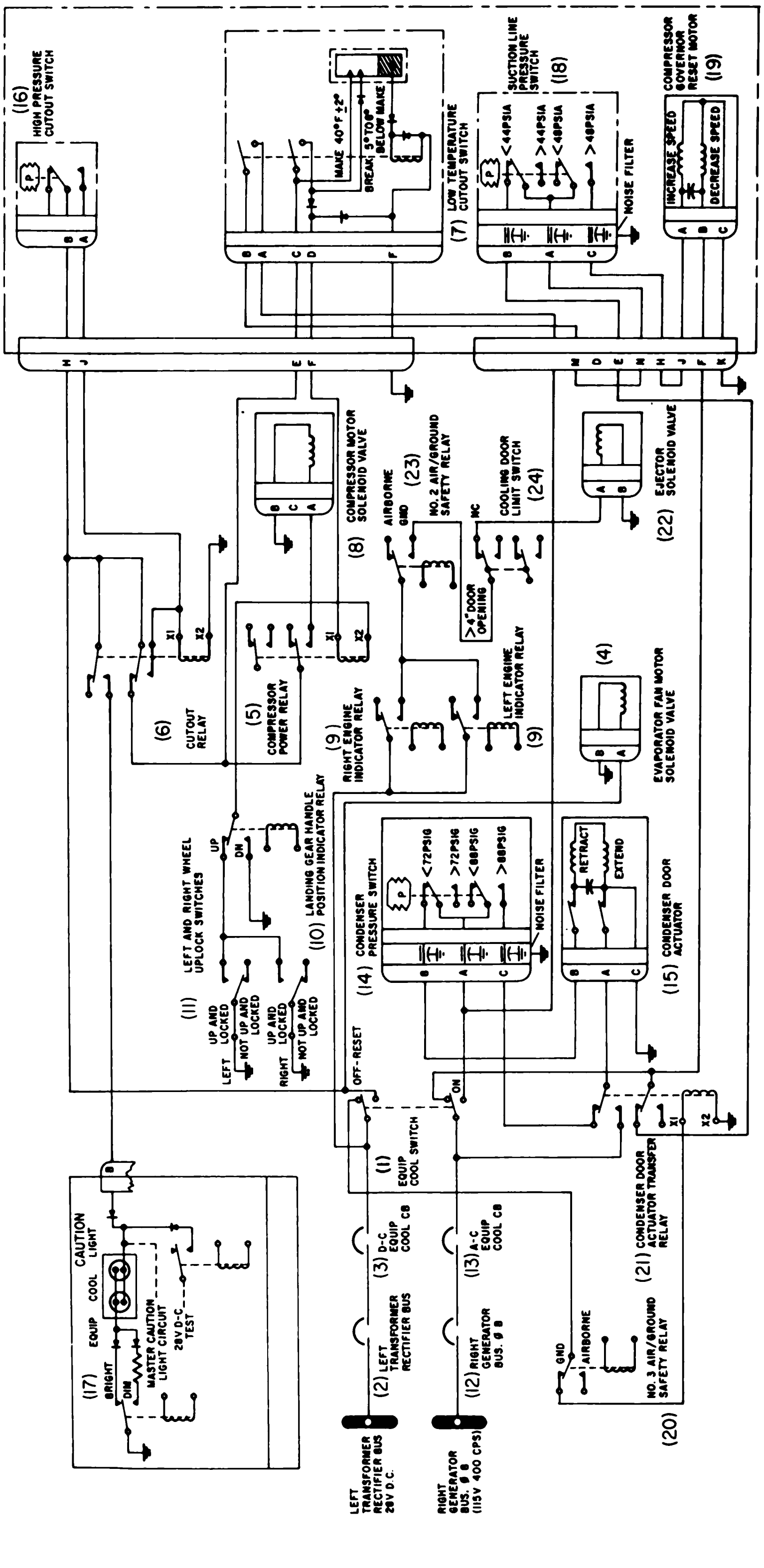


Figure 15-9.—Vapor cycle system schematic.

thereby increasing ram airflow through the scoop and the condenser assembly. The increased ram airflow through the condenser assembly lowers refrigerant temperature and causes a corresponding decrease in refrigerant pressure. If refrigerant pressure is less than 72 psig, the condenser pressure switch (14) permits 115 volts a.c. to energize the condenser door actuator (15) to retract. As the actuator retracts, it closes the flap door, thereby decreasing ram airflow through the condenser assembly. When refrigerant pressure is within 72 to 88 psig, the condenser pressure switch opens a circuit to deenergize the actuator.

From the condenser assembly, the liquid refrigerant flows to the receiver in the evaporator group assembly. (See fig. 15-8.) The receiver stores surplus refrigerant and thereby prevents surges in the refrigerant flow rate. The temperature of the liquid refrigerant flowing from the receiver is further reduced in the subcooler to prevent flashback to a vapor state before the refrigerant reaches the thermostatic expansion valve. Before entering the thermostatic expansion valve, the refrigerant passes through a filter-drier and a refrigerant sight glass. The filter-drier removes water and other foreign matter from the liquid refrigerant. The sight glass provides a visual indication of refrigerant flow. The refrigerant is metered by the thermostatic expansion valve prior to entering the evaporator assembly.

The hydraulically driven evaporator fan forces warm compartment air through the evaporator assembly at a rate of 55 to 75 pounds per minute. The air is cooled to 3.3° ±2.7°C (38° ±5°F) by transfer of heat from the air to the refrigerant. The cooled air passes through the air filter and enters the header assembly, which directs the cooled air to the avionics equipment. The refrigerant leaves the evaporator assembly as a superheated vapor.

Refrigerant pressure in the evaporator assembly is kept constant by controlling compressor motor speed. If refrigerant vapor pressure in the evaporator assembly increases, the suction line pressure switch (18) at the discharge side of the evaporator assembly energizes the compressor governor reset motor (19) to increase compressor motor speed. This creates a suction in the refrigerant vapor line. The thermostatic expansion valve and the suction line pressure switch maintain refrigerant temperature for maximum heat absorption, regardless of the refrigerant flow necessary to absorb varying heat loads. If the evaporator discharge temperature drops below 0°C(32°F), the low temperature cutoff switch (7) deenergizes the compressor power relay (5) and shuts down the compressor motor, thereby stopping refrigerant flow. The evaporator fan motor continues to circulate compartment air. If the temperature rises to 4°C (40°F), the compressor power relay is energized and the compressor motor operates. From the evaporator assembly, the refrigerant flows through the subcooler and returns to the compressor assembly to repeat the cycle.

The system is turned off by setting the equip cool switch (1) to OFF-RESET. This opens the d-c circuits to the evaporator fan motor solenoid valve (4) and compressor motor solenoid valve (8) and closes the valves to shut down the evaporator fan and compressor motors. When the aircraft is on the ground and the equip cool switch is set to OFF-RESET, 28 volts d.c. are applied through the No. 3 air/ground safety relay (20) to energize the condenser door actuator transfer relay (21). When this relay is energized, it closes a circuit to permit 115 volts a.c. from the left transformer-rectifier bus to energize the condenser door actuator to extend. When extended, the actuator opens the flap door to permit ambient air to cool the condenser assembly.

During ground operation, ram airflow through the vapor cycle scoop is insufficient to cool the condenser assembly, and engine bleed air enters the ejector nozzles in the vapor cycle scoop through the ejector air shutoff valve. (See fig. 15-8.) NOTE: The ejector air shutoff valve is controlled by the ejector solenoid valve (22). The bleed air creates a low pressure area behind the condenser assembly, thereby inducing ambient air to flow through the scoop. The airflow cools the condenser assembly. The ejector air shutoff valve opens when energized by 28 volts d.c. supplied from the left transformer-rectifier bus through the No. 2 air/ground safety relay (23) (when the relay is in the ground position) and the cooling door limit switch (24) (when the flap door is open more than 4 inches).

MAINTENANCE AND INSPECTION

Very little maintenance is required on the pressurization and air-conditioning systems other than making required inspections and operational checks. Most system components are set at the factory and because of the special equipment necessary adjustments cannot ordinarily be made in the field.

It should be remembered that, although the ducting and similar hardware are responsibilities of the AME, these units should also be checked for damage by the AE. Once again, the importance of teamwork between the AE and the AME is emphasized.

ANTI-ICE AND DEFROST SYSTEM

The anti-ice and defrost system on most aircraft that employ the heating system and pressurization system described in this chapter will use the air cycle system as a source of air. The anti-ice and defrost equipment consists of the windshield anti-ice system and the windshield defrost system. Each receives its hot air supply from a common manifold. The anti-icing switch is located on the pilot's temperature-control panel. (Refer to fig. 15-1.)

A windshield overheat thermostat and a shutoff valve in the windshield defrosting duct operate together (in a typical system) to prevent overheating of the windshield. The thermostat opens the valve automatically when the temperature becomes too high; this diverts the hot defrosting air to the air-conditioning outlet at the floor of the cockpit until the temperature is reduced. Windshield overheating occurs only in the event of failure of the cabin air temperature high-limit pickup.

A manual control is provided on the pilot's control panel, for directing the greater proportion of air to the windshield or to the cockpit floor. (See fig. 15-1.) The positions of this control knob, labeled DEFROST-PULL and FOOT AIR-PUSH, provide mechanical setting of a flapper valve in the windshield defrosting duct.

CHAPTER 16

EQUIPMENT CIRCUITS

A large part of the Aviation Electrician's job is the maintenance and repair of the equipment circuits in the aircraft. A complete coverage of all types of equipment used in naval aircraft cannot be provided in this course. However, a selection of representative systems is presented, with the idea that knowledge of some typical circuits will lead to an understanding of the principles underlying all similar types.

ANTI-ICERS AND DEICERS

Anti-icer systems serve the purpose of preventing the formation of ice on propellers, windshields, wing and tail surfaces, and inlet guide vanes of jet engines. Deicers are used to remove ice after it has formed on the leading edges of wings, propellers, and tail surfaces, and to remove ice in carburetors.

GUIDE VANE SYSTEM

The anti-icing system of a jet engine used in current aircraft prevents ice formation on the guide vanes. (See fig. 16-1.) The system consists of a switch in the cockpit, an anti-icing valve mounted on the engine, the necessary tubing to direct the hot air from the compressor stage of the engine to the front frame struts, and inlet guide vanes. The compressor discharge air is regulated by the anti-icing valve.

The anti-icing valve (fig. 16-2) is a solenoid-operated bleed valve. With no electrical input to the solenoid, the bleed valve is closed and there is no anti-icing airflow through the anti-icing valve. When the engine is operating with the valve solenoid deenergized, the main poppet will remain in the closed position. When the solenoid is energized, the solenoid valve is unseated and permits air pressure within the main poppet to escape through the overboard vent.

With pressure decreasing in the poppet valve body, the inlet pressure on the face of the main poppet overcomes spring tension and raises the valve from its seat. This permits the high pressure air to be discharged throughout the outlet of the valve to the anti-icing manifold on the engine. Discharge air from the anti-icing valve is regulated to a constant pressure by the regulating piston and spring.

PROPELLER SYSTEM

One method of preventing an excessive accumulation of ice on propeller blades of reciprocating engines is through the use of electric heaters. Figure 16-3 is a simplified schematic diagram of the system used on the E-1B aircraft.

The propeller deicing system consists of a three-position, two-speed selector switch (propeller deicer switch) and an indicator light, both mounted in the cockpit; a two-speed timer; and two propeller deicer relays (one for each propeller). Also, included (for each propeller) are the brush pad bracket assembly, mounted on the engine nose section; the slip-ring assembly, which is the aft portion of the propeller assembly, and a neoprene rubber heating element and connector for each blade. The blade heaters are protected by abrasion strips. The deicing system is designed to operate at either a slow cycle of 40-75 seconds on, 120-225 seconds off; or a fast cycle of 17-22 seconds on, 51-66 seconds off. The positioning of the switch to FAST or SLOW should be determined according to the icing conditions encountered.

Setting the selector switch to either SLOW or FAST, permits d-c power from the essential bus to energize the deicer timer motor and turn on the indicator light. Resistances in the timer determine the speed of the timer motor. The motor, through reduction gears, causes the cams on the camshaft to rotate, positioning the

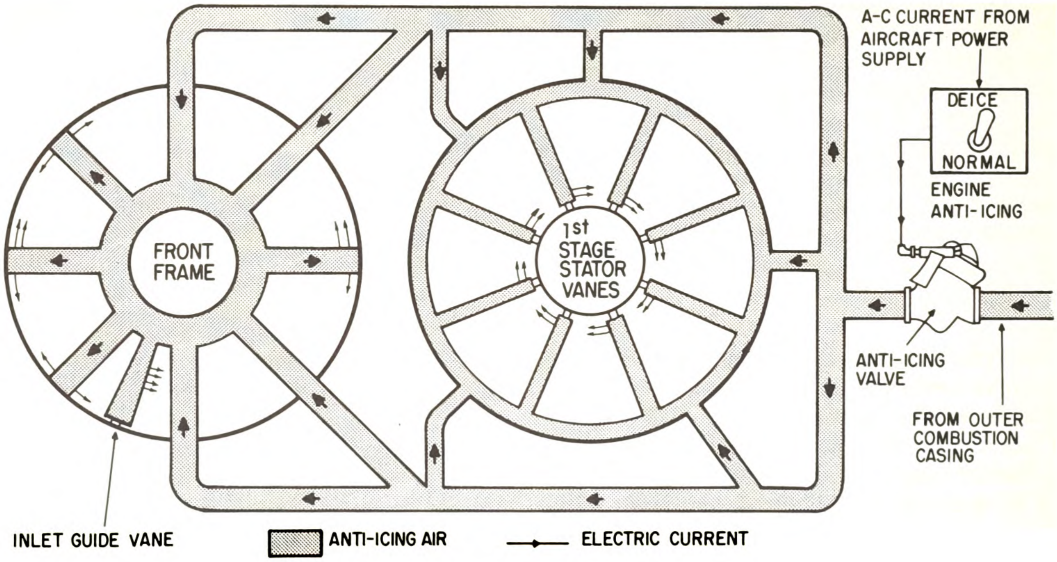


Figure 16-1.—Jet engine anti-icing system.

cam switches alternately between the right and left contacts. Current flows through these contacts to cycle their respective propeller deicer relays. With the relays being energized alternately, current from the 3-phase generator a-c buses, through the 3-phase propeller deicer circuit breakers, flows to the carbon brushes of the propeller brush pad bracket assemblies. These carbon brushes contact the copper sliprings of the propellers and transmit a-c power to the sliprings which transfers it to the blade heating elements. Placing the selector switch in the OFF position stops propeller deicing operation and the indicator light goes out.

The propeller deicer timer is a two-speed, automatic control which regulates, in cycles, the time duration and sequence of electrical impulses to the propeller blade heating elements. The unit is contained in a moisture proof, airtight case and is mounted where it is isolated from extremes of temperature and vibration. The deicer timer consists of a fractional horsepower, constant speed, d-c motor incorporating a reduction gear, a camshaft with three cams, three cam switches, two fixed resistors, and a variable resistor. A filter is also included to minimize radio interference.

Operationally, with the propeller deicer switch set to FAST, direct current flows from the left d-c bus, through the propeller deicer circuit breaker and switch, through pins E, F, and G of the connector plug, to the timer. This current follows two paths in the timer. One path, from pins E and F which are connected in the timer, directs the current flow to the control cam switch, while the other, from pin G, directs the flow through the variable resistor and one fixed resistor to the timer motor, the filter, and to ground. The adjustment of the variable resistor determines the speed of the motor. The motor, through the 3,000 to 1 reduction gear, rotates the camshaft and cams. Two single lobed shift cams and a single two-lobed control cam are secured to the camshaft. They are positioned on the camshaft so that the two single lobed shift cams are on either side of the two lobed control cam. As the control cam is rotated by the motor, it alternately makes and breaks its right and left cam switch contacts. This permits the flow of current to the shift cam switches. (The outboard shift cam switch is inoperative in the E-1B aircraft.) As the current flows to the other shift cam switch, the rotation of the single lobed cam makes and breaks the shift cam switch contacts thus cycling first the right and then the left propeller deicer relays.

With the propeller deicer switch set to SLOW, the operation is identical to the fast cycle with the one exception that direct current enters the timer through a different pin (pin H) in the plug and flows through the two fixed resistors and the variable resistor to the motor, the filter, and to ground. (D-c power to the control cam switch is through the same pins as for the fast cycle.) Because of the increase in resistance, the motor

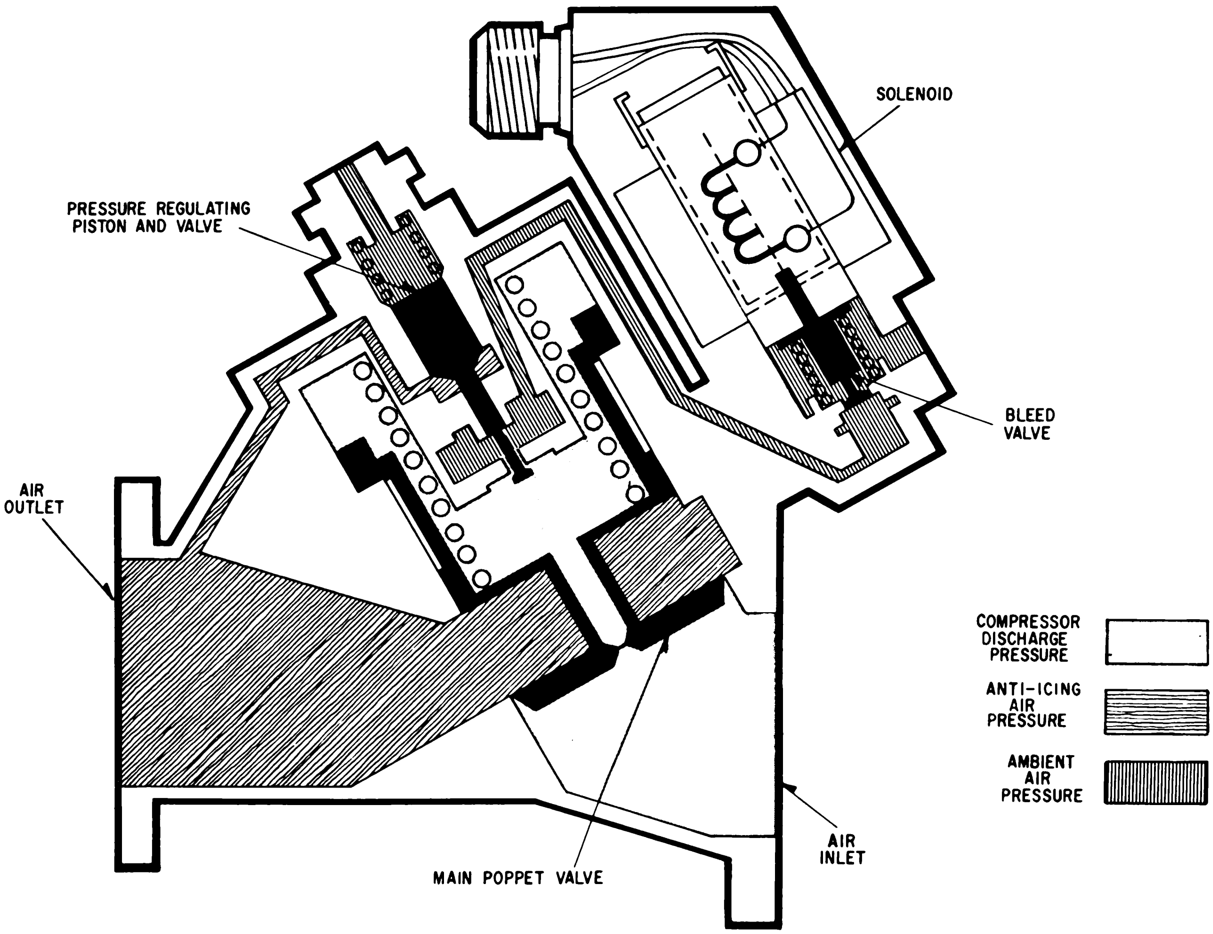


Figure 16-2.—Anti-icing valve.

operates at a slower speed. Thus, with the motor speed reduced, the rotation of the camshaft, through the reduction gear, is slowed and the timer now functions at the slower cycle.

WINDSHIELD ANTI-ICING AND DEFOGGING SYSTEM

An electrical anti-icing and defogging system is provided for the windshield panels in current naval aircraft. The panels are constructed of two pieces of semitempered plate glass laminated with a vinyl plastic core. The core acts as a safety device to prevent shattering in the event of collision with birds when it is in the heated condition. The resistance heating element for anti-icing and defogging consists of a transparent, electrically conductive film, evenly distributed over the inner surface of the outer pane of glass. In addition, the system includes the following:

1. A windshield wire terminal box, located between the windshield panels.
2. A temperature sensing element embedded in each panel.
3. Two windshield autotransformers and a heat control relay.
4. A dual windshield control unit.
5. A windshield heat control toggle switch located in the cockpit.

A typical system as used in the E-1B aircraft is depicted in figure 16-4.

The system is powered from the left generator a-c buses through the windshield heat control circuit breakers. When the windshield heat control switch is set to HIGH, 115-volt,

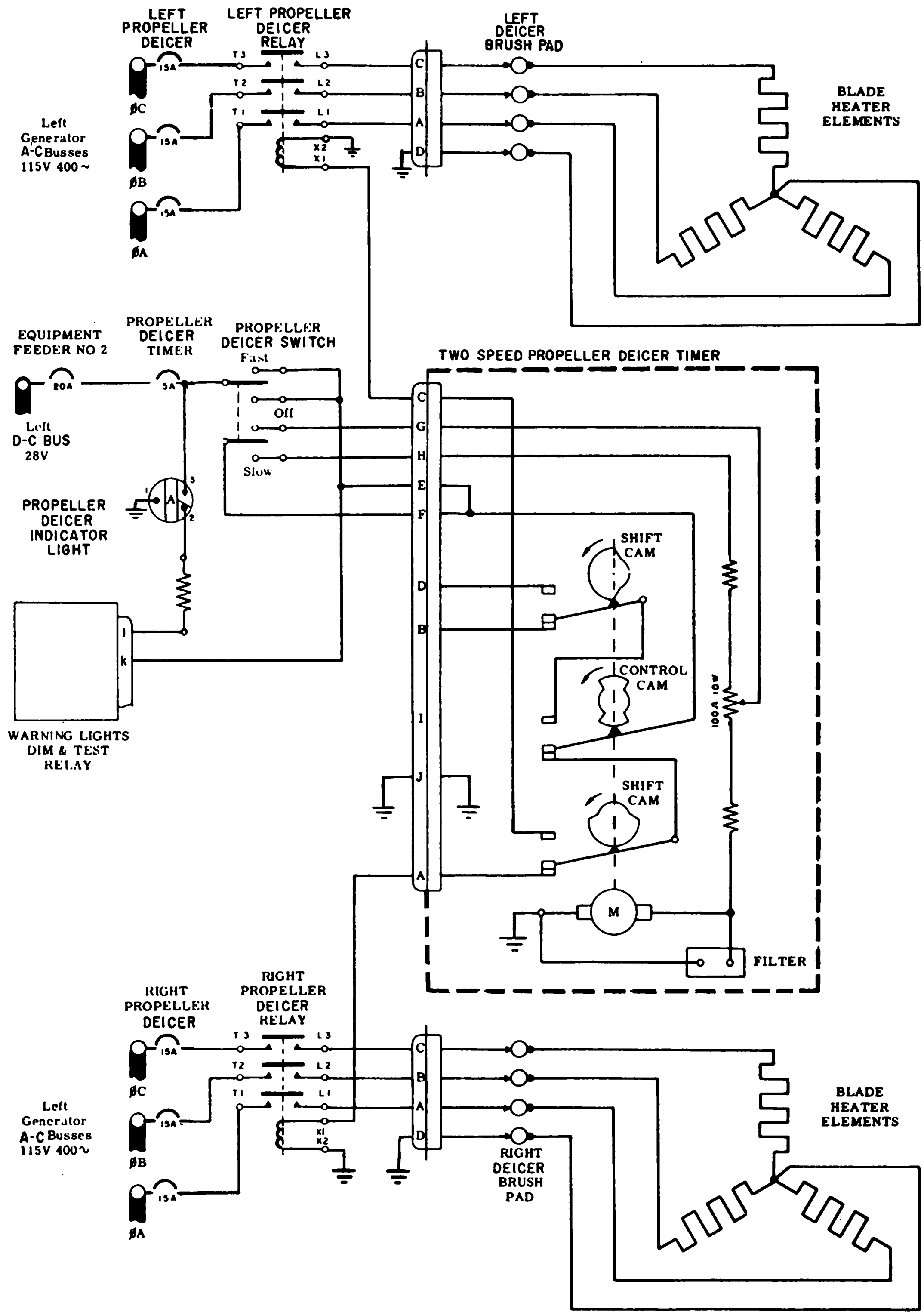


Figure 16-3.—Electrical deicing for a propeller system.

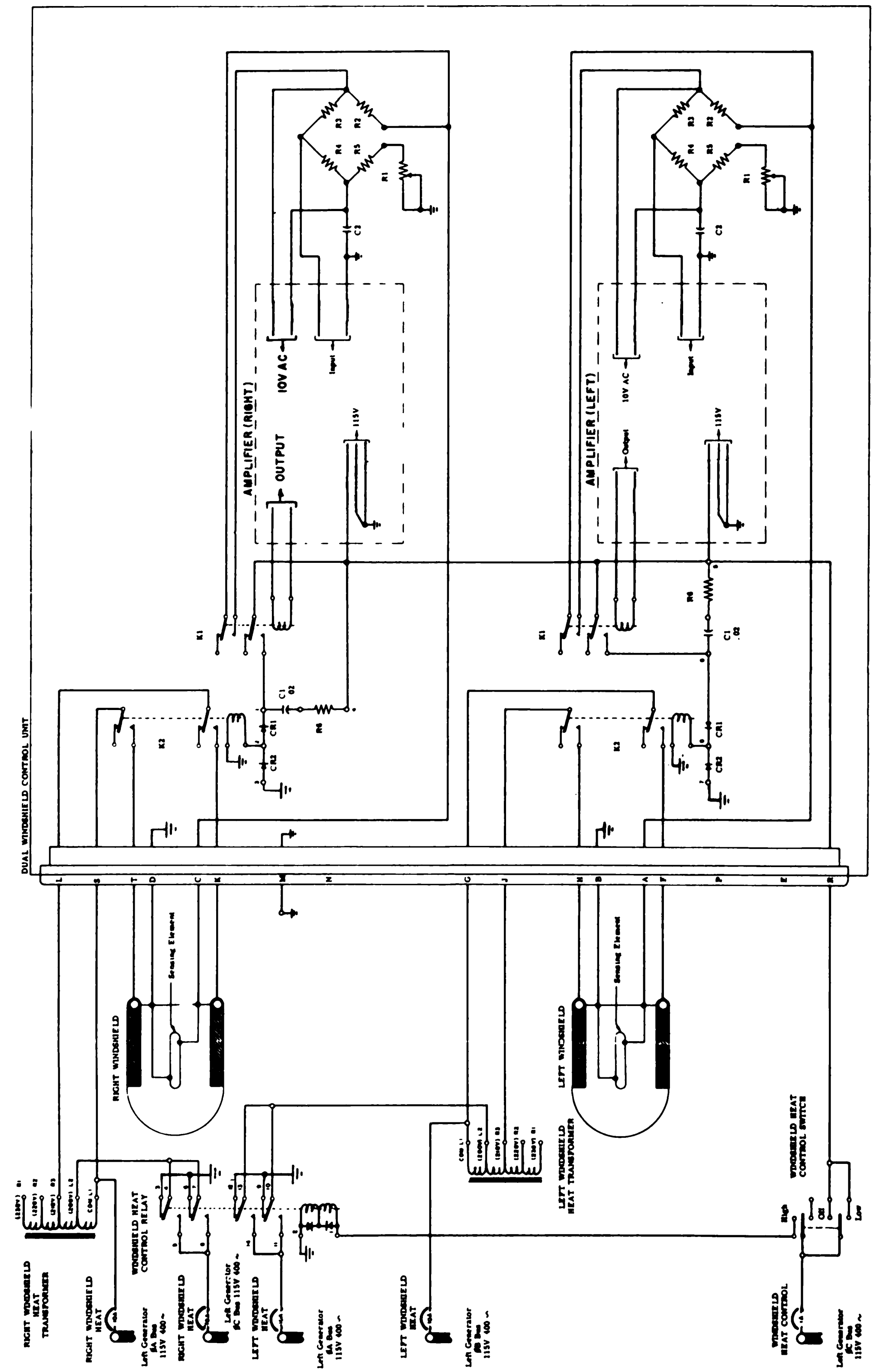


Figure 16-4.—Windshield anti-icing and defogging system.

400-cycle a.c. is supplied to the left and right amplifiers in the dual windshield control unit. The windshield heat control relay is then energized, thereby applying 200-volt, 400-cycle a.c. to the windshield heat autotransformers. These transformers provide 218-volt a-c power to the windshield heating current bus bars through the dual windshield control unit relays. The sensing element in each windshield has a positive temperature coefficient of resistance and forms one leg of a bridge circuit. When the windshield temperature is above calibrated value, the sensing element will have a higher resistance value than that needed to balance the bridge. This decreases the flow of current through the amplifiers and the relays of the control unit are deenergized. As the temperature of the windshield drops, the resistance value of the sensing elements also drops and the current through the amplifiers will again reach sufficient magnitude to operate the relays in the control unit, thus energizing the windshield heaters. When the windshield heat control switch is set to LOW, 115-volt, 400-cycle alternating current is supplied to the left and right amplifiers in the dual windshield control unit and to the windshield heat autotransformers. In this condition, the transformers provide 121-volt a-c power to the windshield heating current bus bars through the dual windshield control unit relays. The sensing elements in the windshield operate in the same manner as described for high heat operation to maintain proper windshield temperature control.

The temperature control unit contains two hermetically sealed relays and two three-stage electronic amplifiers. The unit is calibrated to maintain a windshield temperature of 40°-49°C (105° - 120° F). The sensing element in each windshield panel has a positive temperature coefficient of resistance and forms one leg of a bridge which controls the flow of current in its associated amplifier. The final stage of the amplifier controls the hermetically sealed relay which provides a-c power to the windshield heating current bus bars. When the windshield temperature is above calibrated value, the sensing elements will have a higher resistance value than that needed to balance the bridge. This decreases the flow of current through the amplifiers and the relays of the control unit are deenergized. As the temperature of the windshield drops, the resistance value of the sensing elements also drops and the current through the amplifiers will again reach sufficient magnitude to operate the relays in the control unit energizing the circuit.

WINDSHIELD AND CARBURETOR SYSTEMS

An alcohol deicing system is provided on some aircraft to remove ice from the windshield and the carburetor. Figure 16-5 illustrates a typical two-engine system in which three deicing pumps (one for each carburetor and one for the windshield) are used. Fluid from the alcohol supply tank is controlled by a solenoid valve which is energized when any of the alcohol pumps are on. Alcohol flow from the solenoid valve is filtered and directed to the alcohol pumps and distributed through a system of plumbing lines to the carburetors and windshield.

ON-OFF toggle switches control the operation of the carburetor alcohol pumps. When the switches are placed in the ON position, the alcohol pumps are turned on and the solenoid-operated alcohol shutoff valve is opened. Operation of the windshield deicer pump and the solenoid-operated alcohol shutoff valve is controlled by a rheostat type switch, located in the pilot's station. When the rheostat is moved away

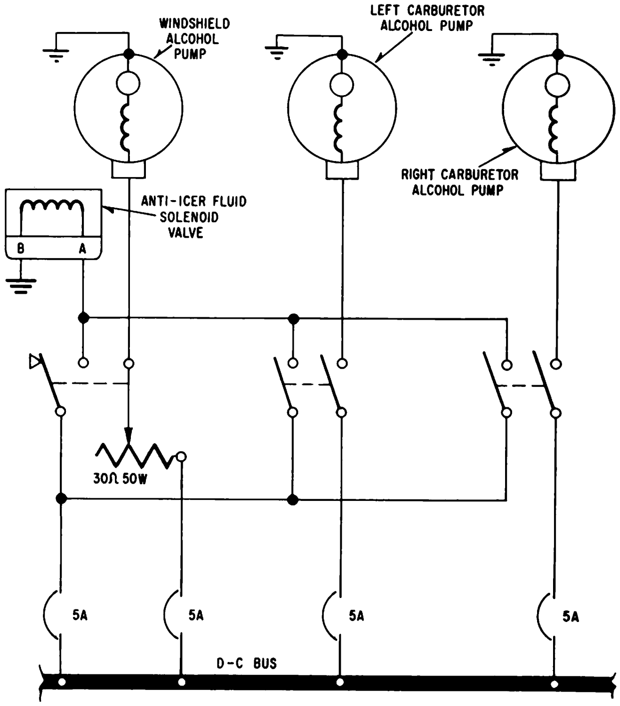


Figure 16-5.—Carburetor and windshield deicing system.

from the OFF position, the shutoff valve is opened and the alcohol pump will pump fluid to the windshield at the rate selected by the rheostat. When the rheostat is returned to the OFF position, the shutoff valve closes and the pump stops operation.

WING AND TAIL ANTI-ICING

Some aircraft are equipped with a thermal anti-icing system that is designed to prevent the formation of ice on the leading edge of the wing panels and tail surfaces by heating the leading edges with hot air. The hot air is supplied by a combustion heater installed in the wings and tail section. Fuel for the anti-icer heaters is obtained by electrically operated pumps. The amount of fuel delivered by the pump is determined by the demands of the heater. In some aircraft, heater demands are determined automatically through the use of thermostats. Fuel flow and airflow may be controlled by various types and combinations of solenoid-operated valves.

WING AND TAIL DEICING

Some aircraft are equipped with air-inflated, rubber deicer boots on the leading edges of wing and tail surfaces. Air pressure or vacuum is alternately applied to these boots and cracks off any ice that has formed. Once the ice has cracked, the force of the airstream peels it back and carries it away. Pressure for inflating the air cells in the deicer boots is normally supplied by engine-driven pumps. Air pressure or vacuum is alternately applied either through the use of a motor-driven rotary distribution valve or the combination of an electronic timer and solenoid distributor valves.

PITOT TUBE ANTI-ICING

In order to prevent the formation of ice over the opening in the pitot tube, a built-in electric heating element is provided. A switch is provided on the pilot's console for controlling power to the heaters; power is taken from the d-c bus. Caution should be exercised when ground checking the pitot tube since the heater must not be operated for long periods unless the aircraft is in flight.

FUEL TRANSFER SYSTEM

Fuel transfer pumps are used to transfer fuel from auxiliary tanks (drop tanks, internal wing tanks, external tanks, etc.) to a main or service tank. In some aircraft, this system simply inclues a motor-driven pump with a manual switch control. Some aircraft use an automatic system in addition to the manual system.

The fuel transfer system employed on the F-4B is discussed in the following paragraphs.

FUSELAGE FUEL TRANSFER SYSTEM

The purpose of the fuselage fuel transfer system is to keep the engine feed cell (fuselage cell number one) supplied with fuel. (See fig. 16-6.) Fuselage cell number two accomplishes its transfer into cell one by gravity only. Fuel in fuselage cell number three gravity flows into cell four and is then pumped into cells one and two. Fuel in fuselage cell number five gravity flows into cell six and is pumped in cells one and two in a similar manner. Check valves located in the discharge port of each pump prevent reverse flow in the event of pump failure. A transfer pump pressure switch is located between each hydraulically driven pump and its check valve. A third pressure switch is located in the common manifold. These pressure switches are energized during the transfer pump checks.

Fuselage cells number four and six each contain an electrically driven fuel transfer pump and a hydraulically driven fuel transfer pump. These four pumps feed a common manifold which transfers fuel into cells one and two.

The flow of fuel from the transfer pump manifold into fuselage cells number one and two is controlled by a transfer level control valve in each cell. Each control valve contains a set of floats and a diaphragm shutoff mechanism. As the cell fills, fuel raises the floats which closes the diaphragm and prevents additional fuel from entering the cell until the fuel level has dropped. The level control valve in cell one utilizes a pilot valve mounted in the front of the cell which contains an additional set of floats to permit fuel transfer when the aircraft is climbing steeply.

NOTE: The hydraulically driven fuel transfer pumps will operate whenever external utility hydraulic power is applied without also applying external electrical power. The reason for this is that the hydraulic fuel pumps control valve is open when deenergized.

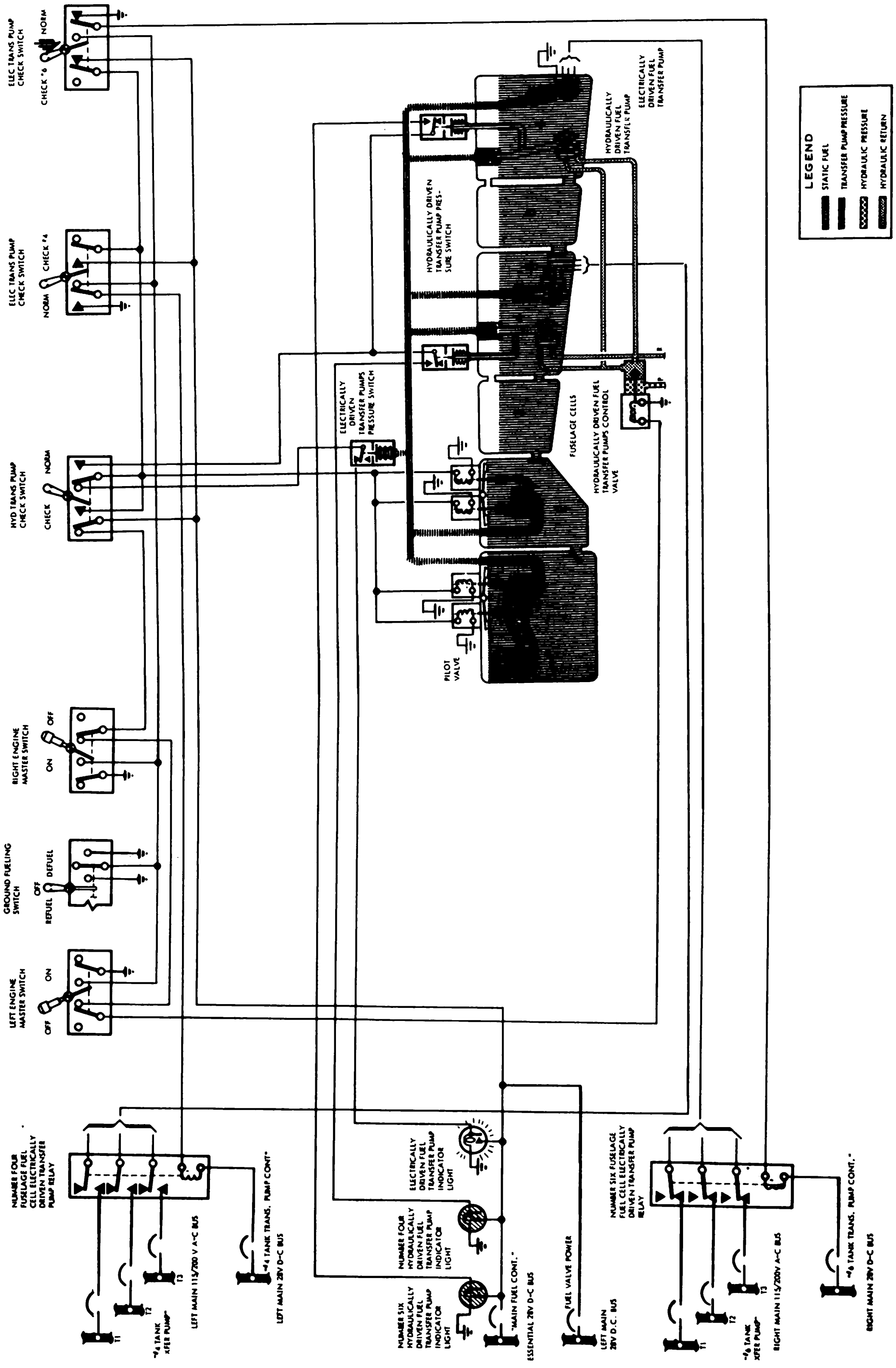


Figure 16-6.—Fuselage fuel transfer schematic.

The transfer pumps may be checked for proper operation and adequate discharge pressure by actuating the transfer pump check switches in the left wheel well.

A pressure of 2 psi is maintained in the fuselage cells during flight. This minimizes fuel boiling and evaporation at high altitudes, and helps insure a positive fuel supply to the engines.

Both hydraulically driven and both electrically driven fuel transfer pumps operate continuously during flight to transfer fuel from fuselage cells four and six to cells one and two. Both electrically driven pumps will operate when either engine master switch on the pilot's left console is placed in the ON position, or when the ground fueling switch located in the right wheel well is placed in either the REFUEL or DEFUEL position. Both hydraulically driven pumps operate when external hydraulic power is applied to the utility hydraulic system, without also applying external electrical power. Both pumps will also operate when external hydraulic (utility) and electrical power is applied and either engine master switch is placed in the ON position.

In addition to the above methods the electrically driven fuel transfer pumps may be operated by actuating the transfer pump check switches in the left wheel well.

INTERNAL WING TANK FUEL TRANSFER AND DUMP SYSTEM

The internal wing tanks are pressurized to 15 psi in order to transfer fuel to the fuselage cells. (See fig. 16-7.) When external electrical power is applied, both internal wing tanks pressure regulators are energized closed. When the landing gear handle is placed in the UP position, the pressure regulators are deenergized open, and the internal wing tanks pressure vacuum relief valves are energized closed, allowing the tanks to pressurize.

Wing fuel is now capable of being transferred to fuselage cells one and three providing certain conditions exist. This fuel cannot enter fuselage cell number one, as fuselage transfer fuel keeps the floats of the level control valve raised. However, if engine consumption exceeds the transfer rate of the hydraulic and electric transfer pumps, the fuel level in cell one will drop the floats of the control valve, and fuel will enter the tank. Fuel from the internal wing tanks will enter cell three as soon as the floats of the level control valve drop.

The internal wing tank dump switch located on the pilot's fuel system control contains two positions, NORMAL and DUMP. Selection of the DUMP position initiates the following sequence of events: The internal wing tanks pressure regulators are deenergized open and the pressure vacuum relief valves energized closed allowing the wing tanks to pressurize. Pressurization occurs regardless of the position of the landing gear handle. The internal wing tanks transfer valves energize close, stopping all internal wing fuel transfer to the fuselage cells. The internal wing tanks electric motor operated dump valves are opened and wing fuel under pressure is forced through the wing tank dump masts at the trailing edge of the wing. The selection of the internal wing tank dump switch to the NORMAL position returns the affected components to their original positions prior to dumping of wing tank fuel.

EXTERNAL FUEL TRANSFER SYSTEM

All external fuel is transferred to fuselage cells one and three by manual selection of the external transfer switch located on the pilot's fuel system control panel. (See fig. 16-8.) This switch has three positions, OUTBD, OFF, and CENTER.

With the selection of the external fuel transfer switch to the OUTBD position, the following action takes place. Both left and right external wing tanks fuel shutoff valves open, allowing fuel transfer to commence. The internal wing tank fuel shutoff valves (both inboard and outboard) close, to prevent transfer of internal wing fuel at the same time external fuel is transferring. A fuel flow switch in each external tank's transfer line energizes an indicator light in the pilot's cockpit when fuel flow through the switch drops below a certain value. This signal indicates that the tank has either emptied or a transfer malfunction has stopped fuel flow from the tank. The flow switch also functions during refueling, and energizes the warning light when fuel flow into the tank has stopped. The external wing tanks may be jettisoned by selecting the JETT position of the external tanks switch on the pilot's fuel system control panel. If the external transfer switch is left in the OUTBD position when the external wing tanks are jettisoned, the external wing tanks fuel shutoff valve will close, and the internal wing tanks fuel shutoff valves will open, allowing wing fuel to transfer as soon as the external tanks drop. A self-positioning quick-disconnect is provided at the fuel connection for

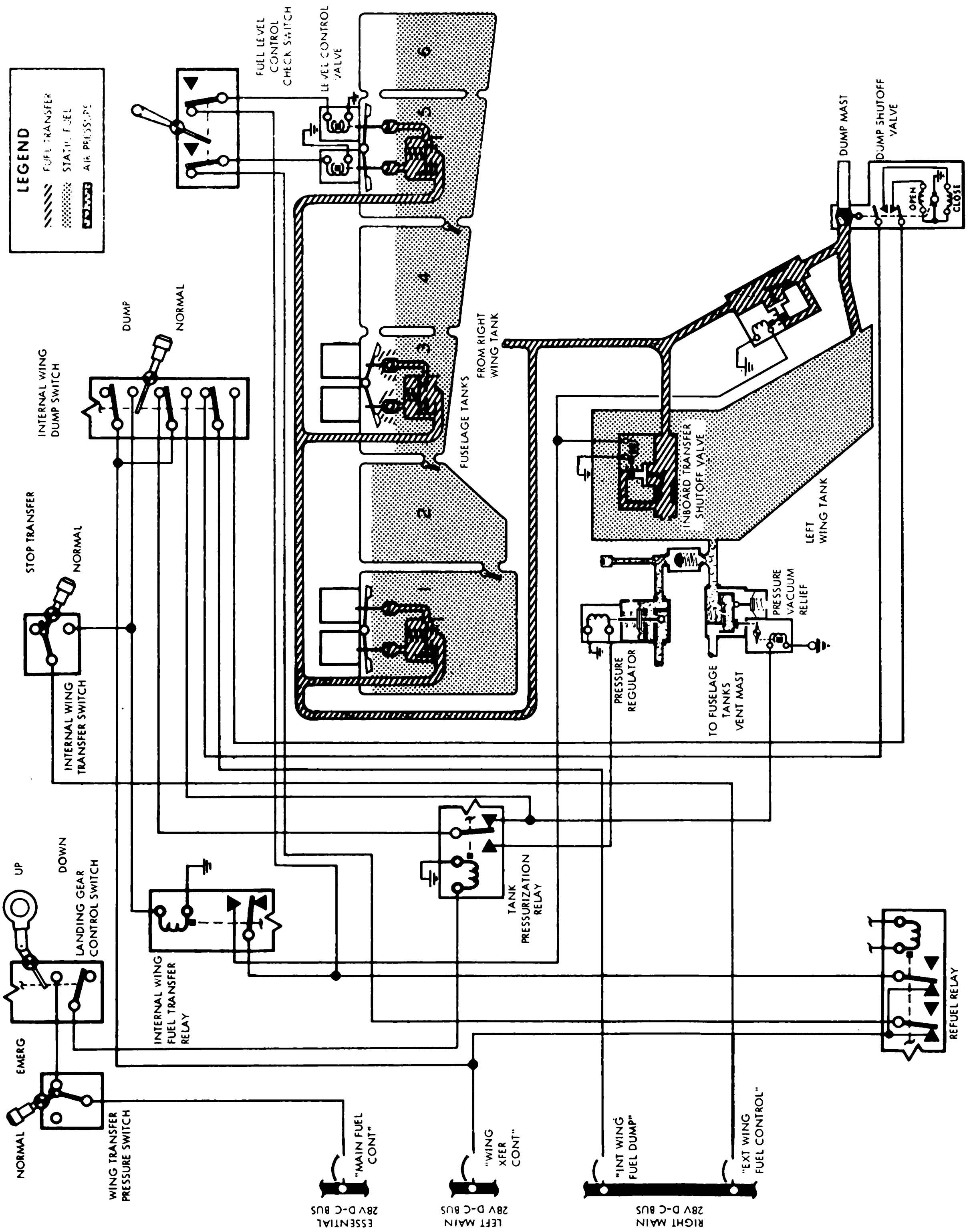


Figure 16-7.—Internal wing fuel transfer and dump schematic.

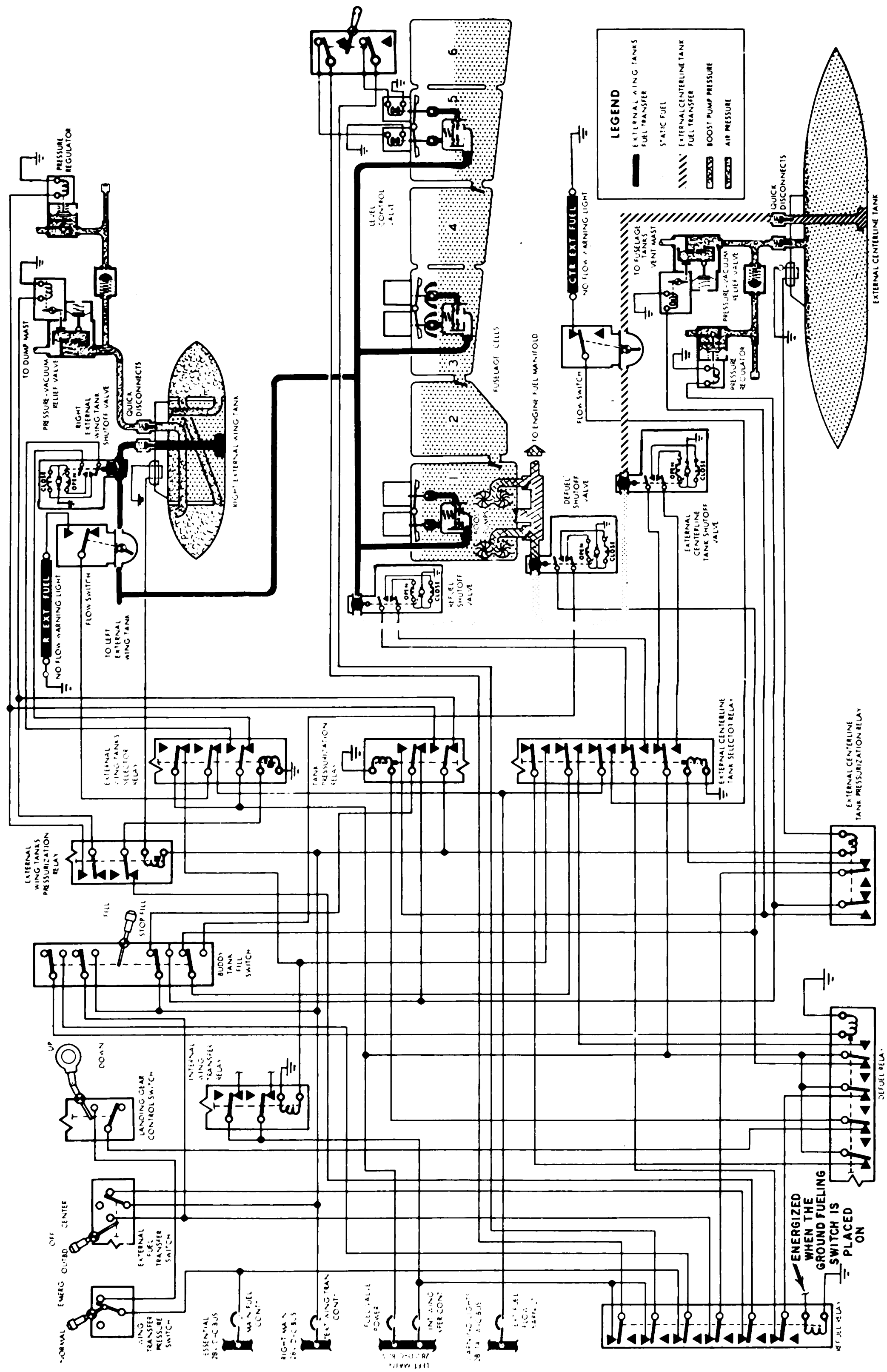


Figure 16-8.—External fuel transfer schematic.

each external wing tank to prevent loss of fuel in the event of a shutoff valve malfunction.

With the selection of the CENTER position of the external transfer switch, the following action takes place: The centerline fuel shutoff valve and the refueling shutoff valve both open, allowing the fuel to transfer from the centerline tank to the fuselage cells in the same manner that fuel transfers from the external wing tank. The internal wing tanks fuel shutoff valves (both inboard and outboard) close, to prevent transfer of internal wing fuel at the same time centerline fuel is transferring. When the external centerline tank is empty, a float lowers in the bottom of the tank closing the tanks fueling valve to prevent pressurizing air from entering the aircraft's fuel system. A fuel flow switch in the tank's transfer line energizes an indicator light in the pilot's cockpit when fuel flow through the switch drops below a certain value. This signal indicates that the tank has either emptied or a transfer malfunction has stopped fuel flow from the tank. The flow switch also functions during refueling, and energizes the warning light when fuel flow into the tank has stopped. The external centerline tank may be jettisoned by depressing the ext stores center release switch on the left subinstrument panel; or depressing the centerline stores release switch on the control stick, providing the armament selector switch is in the proper position. If the external transfer switch is left in the CENTER position when the external centerline tank is jettisoned, the centerline fuel shutoff valve and the refueling shutoff valve both close, and the internal wing tanks fuel shutoff valves will open, allowing wing fuel to transfer as soon as the centerline tank drops. A self-sealing quick-disconnect is provided at the fuel connection for the centerline tank to prevent loss of fuel in the event of a shutoff valve malfunction.

PUMP MAINTENANCE

Transfer pumps are built as integral units in that the pump and electric motor are built together. Thus, when a pump unit becomes inoperative due to an internal open circuit, poor commutation, or fuel leakage into the motor, it is normally removed and returned to an overhaul activity. When an open circuit is suspected, check the supply voltage at the motor leads before replacing the pump. The electrician will normally perform only power and control circuit repairs and maintenance. The pump assemblies are normally removed and returned to an overhaul activity for bearing replacement and complete overhaul after a specified period of operation.

LANDING GEAR CONTROL

Most naval aircraft are equipped with a hydraulically actuated, electrically controlled landing gear. Locking of the landing gear in either the retracted or extended position is normally accomplished automatically. Figure 16-9 is the electrical schematic of the landing gear control circuit of a patrol type naval aircraft.

CIRCUIT OPERATION

The landing gear circuit incorporates an electrical, solenoid-operated selector valve to control hydraulic actuation of the landing gear. Current is supplied to the landing gear selector valve through two SPDT limit switches. These switches are actuated by a cam on the landing gear control lever, permitting current to flow to either the up or down coil of the valve, depending on the position of the control lever. The landing gear control circuit also incorporates electrical control for emergency extension of the nose gear with emergency hydraulic system power. A center-off switch (SPDT type) provides control of a double solenoid-actuated hydraulic selector valve. The center-off position of the switch is the normal position during operation of the landing gear with the main hydraulic system. The down position selects emergency hydraulic system power for nose gear extension. The bypass position is used only during retraction of the nose gear with main hydraulic power after it has once been extended by emergency hydraulic power, and at any other time when it is desired to release emergency system hydraulic pressure.

ADDITIONAL CIRCUITS

In some aircraft the landing gear control circuit also controls the supply of power to the propeller-reversing circuit through left and right main torque-link switches, to the stores release circuit (through left main torque-link switch) and to the bomb-bay door control circuit (through nose gear down sense switch). The left main gear torque-link switch supplies power to energize the landing gear control lever locking

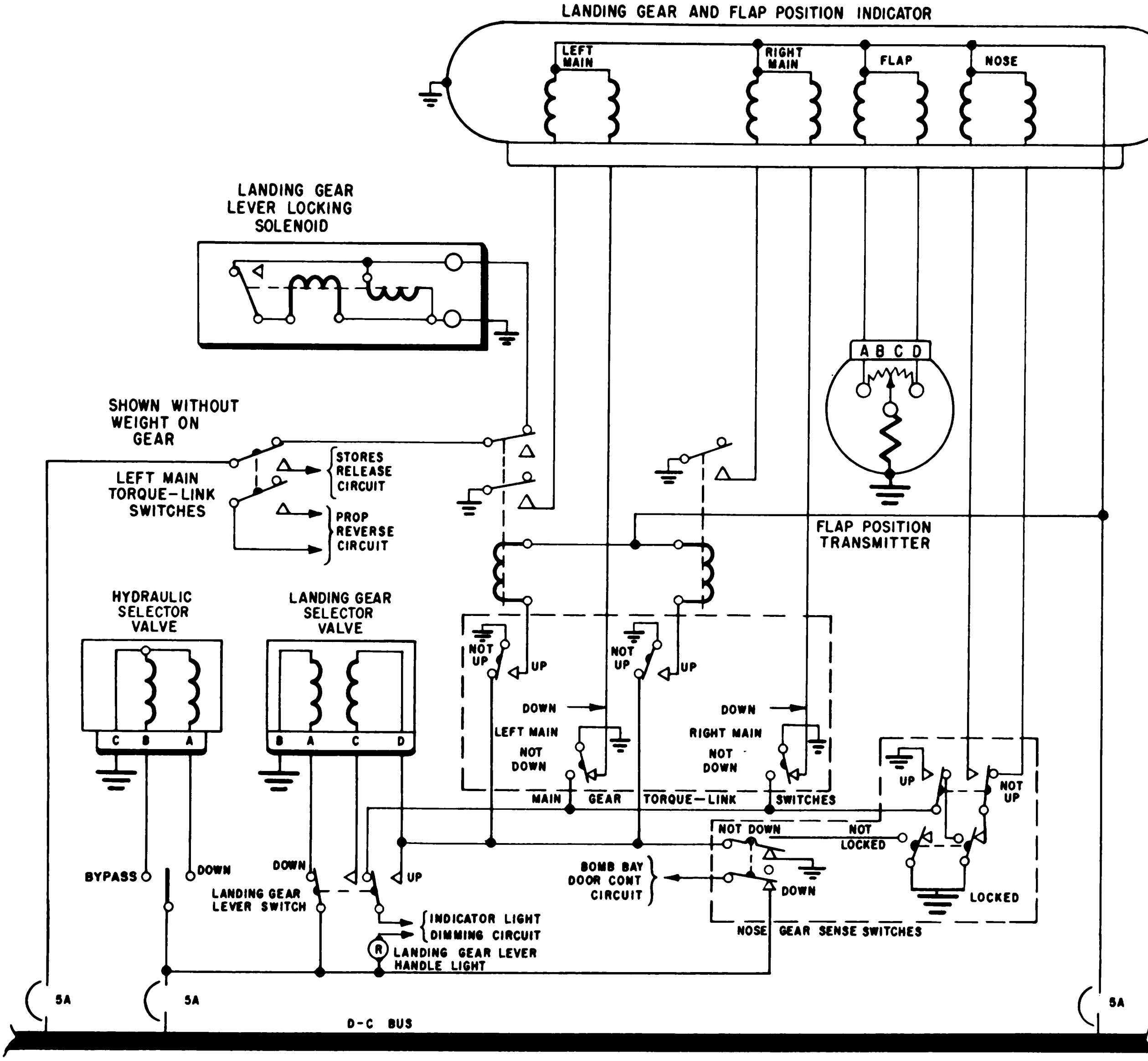


Figure 16-9.—Landing gear control circuit.

solenoid. The weight of the aircraft must be removed from the landing gear shock strut before the landing gear control lever may be moved away from the wheels down position. The solenoid will be deenergized after the gear retracts by the up sense switch of the left main gear; this switch energizes a relay, the normally closed contacts of which are in series with the solenoid circuit. The left and right main gear torque-link switches (parallel connected) are wired in series with the power to the throttle lever-locking solenoid to prevent the throttles from being placed in reverse propeller range until either of the torque-link switches is actuated (by aircraft weight compressing one or both main landing gear strut oleos). The left main landing gear torque-link switches (series connected) also open the stores release circuit so that inadvertent release of wing station external stores is prevented when the weight of the aircraft has compressed the shock strut oleo.

A solenoid is installed under the pilot's console to mechanically prevent movement of the landing gear control lever from the wheels down

position when the weight of the aircraft is on the gear. When the weight of the aircraft is on the landing gear, this solenoid is deenergized since the left main gear-torque-link switches are open, allowing the solenoid armature pin to protrude outboard. This position of the solenoid armature pin mechanically prevents movement of the landing gear control lever from the wheels down position to prevent retraction of the landing gear when the aircraft is on the ground. The solenoid armature pin may be depressed manually for emergency or test procedures to allow movement of the control lever.

That portion of the bomb-bay door control circuit, which is provided power through the nose gear down sense switch, is used to switch power for illuminating the bomb-bay "doors-open" warning light when the bomb-bay doors are opened with the alternate bomb-bay door switch and emergency hydraulic system power.

GASOLINE HEATERS

The heating equipment furnished by the manufacturer for application in a particular aircraft is designated as a heater package. The package consists of a basic heater assembly and sufficient accessories to provide an operating unit. The heaters use aviation gasoline for fuel and are similar in construction and operating principles. The major differences between heaters are confined to the methods of taking in and exhausting combustion air, introducing fuel, and to the locations of units and accessories incidental to the operation of the basic heater assemblies.

BASIC HEATER COMPONENTS

In order to produce a heating system, the following items are required:

1. A basic heater assembly.
2. A source of fuel controlled by solenoid valves, fuel pressure regulator, and fuel filters.
3. An ignition unit.
4. Thermal switches.
5. A pressurized supply of air by fan or by outside air scooped into heater.
6. An exhaust outlet.
7. Controlling switches and relays.

Aircraft heaters are designed specifically to supply heat for cabins, cargo space, thermal anti-icing, windshield anti-icing, and instrument heating. The heaters produce heat by burning fuel in a combustion chamber. Both fuel and air required for combustion are carefully measured and maintained in proper proportion by the accessory equipment. The accessory equipment must perform the following functions:

1. Filter the liquid fuel used by the heater.
2. Regulate the pressure of the fuel supplied to the heater.
3. Turn on and turn off the heater's fuel supply in response to heat requirements.
4. Produce ignition for the fuel-air mixture.
5. Exhaust outlet to port fumes outside the aircraft.

SYSTEM OPERATION

Fuel is supplied in most cases from the fuel pressure lines which supply the aircraft engines. Various types of electrical shutoff valves are used in different installations to control the flow of fuel to the heating equipment. When the fuel supply solenoid valve is open, liquid fuel is forced through a spray nozzle into the combustion chamber where it is ignited. When the fuel supply valve is closed, the fuel supply is cut off and the heater ceases to operate.

Electric current for ignition is supplied by a high-potential ignition unit operating from the 28-volt, d-c aircraft power supply. The ignition unit consists chiefly of a vibrator and step-up coil which produces a high-voltage spark at high frequency. The lead used to connect the step-up coil to the spark plug is sealed for radio noise elimination, as the ignition is on continuously during heater operation. On most heaters, the sparkplug used has a long center electrode, and a separate ground electrode is installed in the spray type head. The spark gap is approximately five-sixteenth inch, and provision is made for adjusting the spark gap by providing washers of various thicknesses under the ground electrode. In some installations the fuel vapor is ignited by a glow coil igniter (resistive heating element) operating from the 28-volt, d-c power supply. When the glow coil is used, a thermal switch is mounted in the ventilating airstream to open the circuit to the igniter when the ventilating air reaches a predetermined temperature. However, after once being ignited, the fuel continues to burn.

To prevent overheating of the combustion chamber and radiator assembly, each heater installation requires a thermal switch installed in the ventilating airstream, downstream from the heater. This switch causes the fuel solenoid valve to close when maximum safe temperatures have been reached.

Figure 16-10 shows a heater installation that is used in some naval aircraft. Two switches control the heating and ventilating system. The HI-OFF-LOW heater switch controls the operation of the heater, and the fan switch controls the operation of the heater fan. When only ventilation is desired, the fan switch is operated. This switch energizes the fan relay which connects the fan to the 28-volt, d-c source. The fan switch operates the fan in the heater system but not the heater; therefore, cool air is circulated through the heater system ducts.

When heated air is desired, the heater switch is placed in either HI or LO with the fan switch OFF. The heater fan operates automatically with the heater. A thermal override switch is used to keep the heater air blower in operation until the heater is completely purged of residual exhaust gases after the heater is turned off.

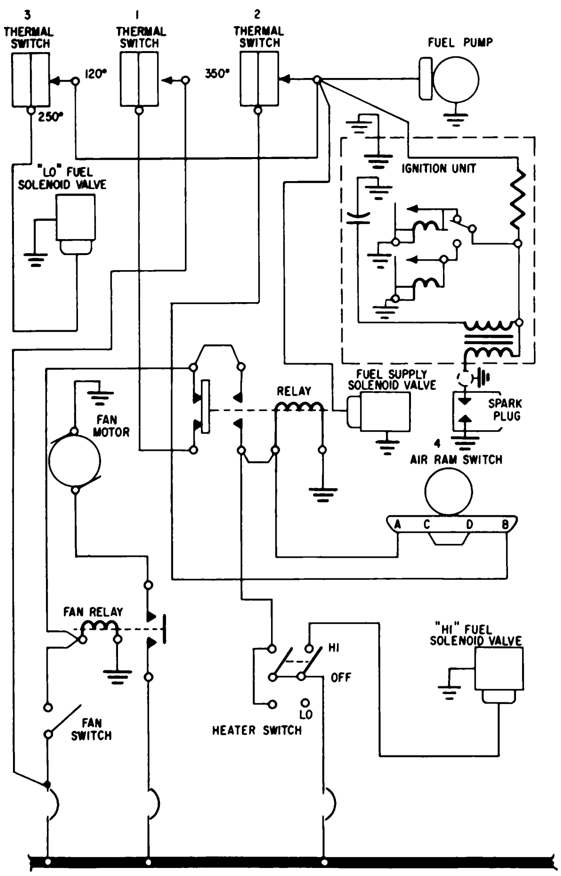


Figure 16-10.—Electrical schematic, combustion heater.

If the heater switch in the cockpit is in the HIGH position, fuel flows from the tank through both the LOW and HIGH solenoid valves, through the metering nozzle, and then into the heater. If the heater switch is in the LOW position, fuel flows only through the LOW solenoid valve. From the mixing chamber, air and fuel enter the combustion chamber. Ignition is accomplished by a spark plug type ignition unit. The burning gases and resulting vapors are conducted the length of the combustion chamber, through passages to the outer chamber for reverse flow, and then to the exhaust outlet on the side of the heater. The fan assembly located at the aft end of the heater circulates air through the system. An overheat thermal switch incorporated in the heater cuts off the solenoid supplying fuel if the heater exceeds the temperature for which it is set. An air pressure switch cuts off the fuel supply to the heater if the fan fails to operate. This is a precaution to prevent an overheated condition and possible fire.

In some installations a fan is not used since the air that is heated and circulated is brought into the aircraft from the outside by means of an airscoop. This air is passed around the heating surfaces and then circulated to the parts of the aircraft where heat is desired. In this system, electric fans are not used as the air picked up by the airscoop has sufficient pressure for circulation. When ground checking an aircraft that uses ram air pressure, a supply of air must be provided by a ground blower; this air must be strong enough to activate the pressure switch.

CAUTION: The ignition of fuel vapor from the fuel used in the gasoline heater can occur from static sparks, sparks from tools, hot exhaust pipes, or electrical circuits. Use extreme safety precautions when working with or around the fuel lines. Use nonspark tools whenever the presence of combustible vapor is suspected. Secure all electrical circuits before working with any fuel lines in the heater.

Do not operate the heater without the combustion fan operating; the gases of combustion are poisonous.

FIRE DETECTORS

The engine fire detector system is an electrical system for detecting the presence of fire, or dangerously high temperatures, in the vicinity of the engines. The system for each engine consists basically of several sensing elements, a control unit, a test box, a test relay, a signal

lamp, and a test switch. The detector utilizes either a continuous strip of temperature-sensing elements or a number of thermocouples in order to cover fully the paths of airflow in a compartment that is a fire hazard.

Figure 16-11 depicts a fire warning system used in the A-6A aircraft.

There are two identical engine fire warning systems installed, one for each engine. The system is of the continuous-element, resetting type, and the sensing element consists of two parallel conductors separated by a semiconductor. The sensing element winds through the engine compartment, where excessive temperature rises are most likely to occur. If an engine fire occurs, the resistance of the semiconductor decreases because of the temperature rise, grounding the central conductor. Under these conditions, relay K101 energizes and the fire warning and test lights go on to warn the pilot of fire. The fire warning test switch on the master test panel, is used to test the fire detection control and the fire warning and test lights. When this test switch is pressed, a relay operates which grounds the central conductor of the sensing element thus simulating a fire condition and lighting the fire warning and test lights. The main components of this

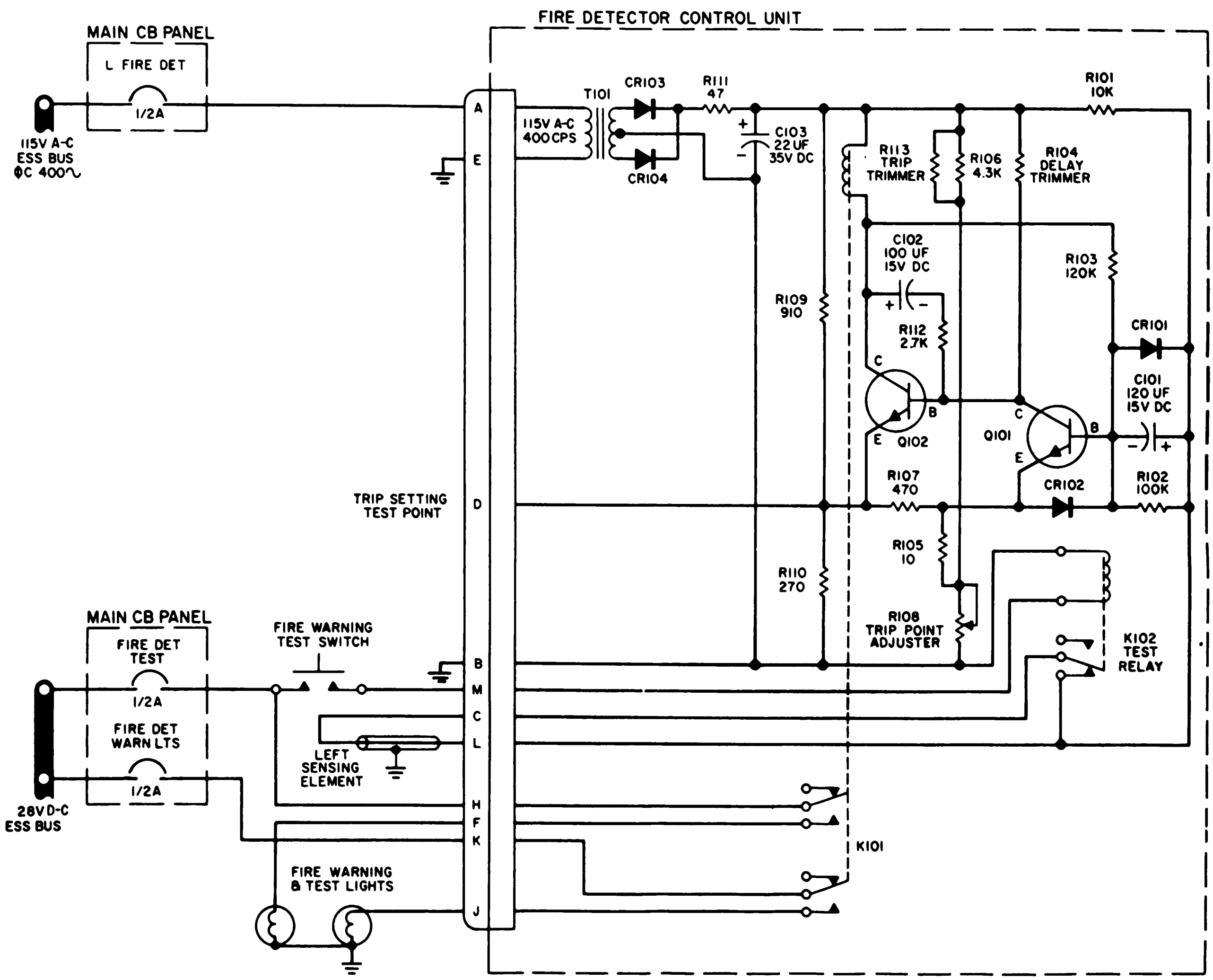


Figure 16-11.—Engine fire warning schematic.

system are the fire detector control unit, fire detector sensing element, fire warning test switch, and the fire warning and test lights.

The control unit is an integral component of the aircraft fire detector system. The unit continuously monitors the electrical resistance of the fire detector system's sensing element. The sensing element is a thermistor device with electrical resistance properties that vary inversely with the temperature; as the temperature increases, the resistance of the sensing element decreases. It is these resistance changes of the sensing element that are monitored by the control unit. The control unit will activate a fire warning light when:

1. The resistance of the sensing element decreases to the predetermined level (established by the fire alarm setting) due to an increase in temperature.

2. The sensing element resistance decreases at a predetermined rate due to the rate of temperature increase in the sensing element.

The control unit, which is hermetically sealed, monitors the resistance of the sensing element with a resistance-bridge measuring circuit. The sensing element forms one side and the trip-point adjusting resistor forms the other side of the resistance-bridge circuit. The bridge null detector is the first stage of a transistor flip-flop circuit. As the sensing element resistance decreases to the null-producing alarm value, the first stage transistor of the flip-flop cuts off, causing the second stage transistor to conduct. The second stage transistor collector current energizes the relay coil; and, the relay contacts complete the warning signal circuit.

The bridge circuit consists of resistors R101, R106, R108 and the sensing element. Trip-adjusting resistor R108 adjusts the bridge circuit to balance at the desired trip resistance of the sensing element, which is 300 ohms. Transistors Q101 and Q102 form the flip-flop circuit.

When the sensing element is in a high resistance state, which exists during normal operating temperatures, the base voltage of transistor Q101 is sufficient to cause the transistor to conduct. With the transistor Q101 conducting, as a result of the voltage drop across the resistor R104, the bias voltage on the base of transistor Q102 is maintained below the cutoff value.

When the resistance of the sensing element decreases, due to increasing element temperature, to the value that balances the bridge circuit, diode CR101 conducts, decreasing the base voltage of transistor Q101 to cutoff. With the transistor Q101 cutoff, the voltage drop across resistor R104 is reduced and the bias for transistor Q102 increases, causing Q102 to conduct. The flip-flop or switch action, is created by providing positive feedback to the emitter of transistor Q101 which is obtained by the current flow through resistor R107. When transistor Q102 conducts, its collector current energizes the coil of relay K101. The relay contacts complete the fire warning signal circuit.

When the sensing element returns to a high resistance state as a result of decreased element temperature, the base voltage of transistor Q101 increases sufficiently to cause the transistor to conduct. This results in a voltage drop across resistor R104 causing the bias voltage on the base of transistor Q102 to decrease to the cutoff value. When transistor Q102 is cut off, the coil of relay K101 is deenergized and the relay contacts open the warning signal circuits.

The bridge circuit of the control unit is modified by incorporating a rate circuit, which provides a control unit that responds to a rate of temperature rise as well as to fixed temperature. The rate circuit consists of parallel-connected capacitor C101, resistor R102 and CR101 connected to the base of transistor Q101. This modification of the circuit enables the control unit to complete the warning signal when the sensing element resistance decreases at a predetermined rate as well as when the sensing element resistance decreases to the predetermined trip resistance.

Capacitor C101 is initially charged as a result of the potential difference which exists between the sensing element and the bias of transistor Q101. A rapid decrease in sensing element resistance will cause voltage applied to the sensing element also to decrease rapidly. Capacitor C101, discharging to maintain the potential difference, drives transistor Q101 into cutoff and initiates the flip-flop action. Transistor Q101 remains cut off if the rate of potential charge across the sensing element is maintained and if the potential decreases to the value which causes CR101 to conduct. Diode CR103 minimizes the recovery time of the rate circuit by providing a quick charge path to capacitor C101.

To insure that rapid resistance changes monitored by the control unit are due to sensing element temperature changes only, and not transient changes caused by induced voltages, moisture shunts or other causes, a transient suppression circuit is added to delay completion of the transistor flip-flop action until the resistance change is sustained for a predetermined period of time.

The transient suppression circuit consists of capacitor C102 and resistor R112 connected across the collector and base of transistor Q102. When transistor Q101 is cut off at bridge null, the bias voltage of transistor Q102 begins to increase, but is delayed until capacitor C102 discharges. Therefore, the action of the second stage transistor Q102 is delayed, resulting in a delay in energizing the alarm circuit relay K101. Due to the delay in energizing the alarm circuit the control unit has been provided with voltage test point D to determine the alarm trip resistance, as desired. The initiation of the flip-flop action is indicated the instant the test point voltage starts to increase.

The test relay K101 is an integral part of the sensing element system test circuit and is used to test the continuity of the sensing element system, and the integrity of the control unit and alarm circuit. The voltage supply to the control unit is obtained from a 115v a-c, 400 cps power source and introduced into the primary of transformer T101. Full wave rectification of the alternating current is obtained by the use of the diodes CR103 and CR104, providing approximately 15v d.c. to the control unit circuit.

OIL DILUTION AND DIVERTERS

The purpose of the oil dilution system is to inject gasoline from the fuel lines into the engine oil system. Oil dilution is used whenever a cold weather start of a reciprocating engine is expected. It is accomplished prior to stopping the aircraft engine. Oil dilution thins the oil that is left in the engine and greatly reduces the cranking torque of the next engine start.

Figure 16-12 is the electrical schematic of an oil dilution circuit.

This system is a manually controlled electrical circuit. The oil dilution control switch, located in the cockpit, is of the momentary-on type. When the control switch is held in the OIL DILUTION position the solenoid of the oil dilution valve is energized. Also, the auxiliary fuel pump will start automatically if it is not already operating. This pump supplies the pressure that is needed to force the gasoline into the oil system.

The control switch also energizes the diverter valve relay. This causes the oil diverter valve motor to open the diverter valve. Fuel flows through the oil dilution valve to the oil system, and the diverter valve directs the oil into the warmup compartment of the supply tank. The action of the diverter valve permits dilution of only the oil in the warmup compartment of the supply tank.

Oil returning from the engine flows through the diverter valve either to the warmup compartment, or to the main compartment of the tank. The diverter motor is connected with the diverter valve control circuit; internal limit switches open the circuit when the motor reaches its extreme limits of travel.

When the temperature of the oil in the tank sump is below 130° F, the thermoswitch contacts are closed, energizing the diverter valve relay to complete the circuit to the diverter valve motor; the motor closes the valve port to the tank's main compartment so that oil flows to the warmup compartment. When oil temperature in the tank sump is above 130° F, the thermoswitch contacts open and the diverter valve relay is deenergized. This completes the circuit to the other side of the motor to close the valve port to the warmup compartment so that oil is directed into the main compartment. Automatic control of the circuit is relinquished by the thermoswitch when the oil dilution system is in operation; the oil dilution circuit, when energized, bypasses the thermoswitch and energizes oil diverter relay, thus completing the circuit to the valve motor to divert all oil, regardless of temperature, to the tank warmup compartment.

ENGINE TEMPERATURE CONTROL

The cooling capacity of the oil cooler system in an aircraft is dependent upon the amount of air that is allowed to pass through the cooler. The airflow is controlled by an oil cooler door which restricts the opening of the oil cooler air exit duct under the control of the oil cooler door actuator. (See fig. 16-13.)

The door is operated by a split-field, reversible d-c motor which includes a magnetic

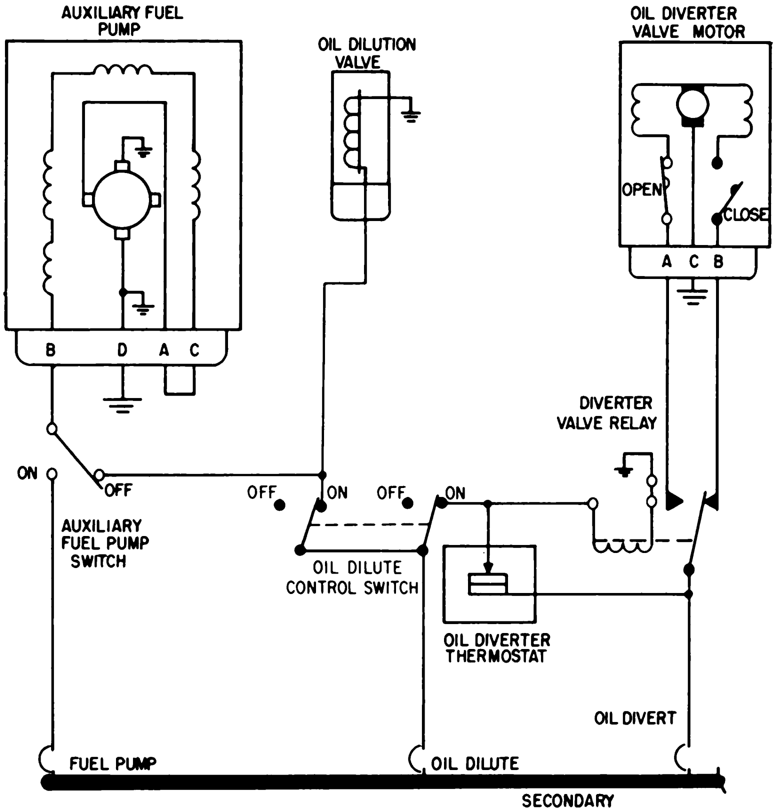


Figure 16-12.—Oil dilution and diverter circuit.

brake to stop the motor quickly when the limits of travel are reached.

The control switch is of the four-position type, with OPEN, CLOSE, AUTOMATIC, and OFF positions. In the OPEN, or CLOSE position, electrical power is directed to the actuator motor and opens or closes the oil cooler door completely. When the switch is placed in the AUTOMATIC position, the actuator is controlled by a thermostat.

The thermostatic control unit is mounted in the oil return line. The unit contains two floating contact arms and a central contact arm that is actuated by a bimetallic coil immersed in the oil of the return line. One of the floating contacts is in the "door open" circuit and the other is in the "door closed" circuit. The two arms rest on a cam which is constantly rotated by a small motor. Thus, the floating contacts are constantly vibrating toward the central contact.

If the oil temperature rises above normal, the thermostatic element causes the central contact to move toward the "door open" contact so that as the contact vibrates it intermittently closes the "door open" circuit. As the actuator is intermittently energized, the door is slowly opened until the oil temperature returns to normal, at which time the central contact moves back to a neutral position.

If the oil temperature falls below normal, the central contact is moved in the opposite direction, causing the door to close. To prevent excessive hunting of the system a tolerance is maintained by adjustment of the cam on the floating contact.

In an extreme case, where the oil temperature rises high above the normal value, the central contact will lift the floating contact clear of the cam, completing a continuous circuit. The door will then move to the full open position where a limit switch in the actuator will break the circuit.

In figure 16-14, another type of engine oil temperature regulator is shown. This regulator employs a mercury-filled thermostat and relays to automatically control the position of the engine oil cooler doors.

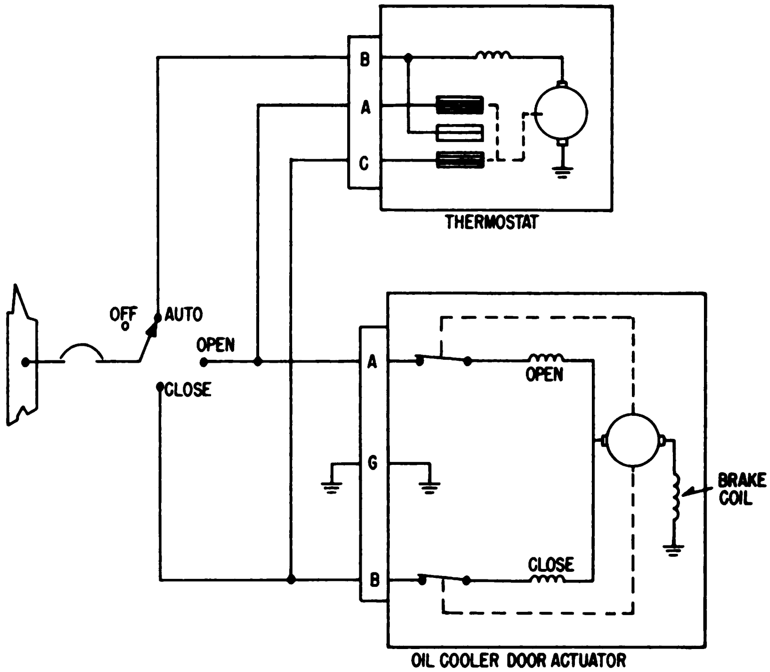


Figure 16-13.—Oil temperature control circuit.

When the engine temperature is low and more heat is required, the two relays are energized and complete a path for current to close the oil cooler door. As the temperature increases the thermostat completes a path to ground, bypassing the relay coils and deenergizing them. Power is then routed through the contact of one of the relays to the open coil of the actuator, causing the oil cooler door to open and reducing engine temperature.

EA-D5 AUTOMATIC TEMPERATURE CONTROL SYSTEM

Another example of an automatic engine temperature control system is the EA-D5 electronic control amplifier which is a servoamplifier operating in the exhaust nozzle control system of Allison J71 turbojet engines. The electronic control operates in conjunction with a set of engine thermocouples and the hydromechanical jet nozzle actuator. System operation prevents engine turbine outlet temperature from exceeding a preselected maximum value.

The amplifier is supplied engine temperature signals from thermocouples installed at the turbine outlet. Within the electronic control, these temperature signals are compared to a reference temperature. This reference temperature is the maximum turbine outlet temperature that should not be exceeded by the engine. Any difference between the engine and reference temperature causes an error signal in electronic control circuitry. This error signal controls voltage supplied to a 2-phase servomotor in the associated hydromechanical jet nozzle actuator.

The hydromechanical jet nozzle actuator schedules minimum engine jet nozzle area as a function of power lever angle. The actuator incorporates provisions for overriding the mechanical minimum area schedule, to permit increasing jet nozzle area and prevent engine over-temperatures. This overriding action is caused by a 2-phase servomotor in the actuator. The servomotor, in turn, operates in response to signals supplied from the electronic control.

When turbine outlet temperature exceeds the reference temperature of the electronic control, exhaust nozzle area is established as a function of engine temperature. Under these conditions, jet nozzle area correcting signals are supplied from the electronic control to the actuator servomotor. Servomotor action causes

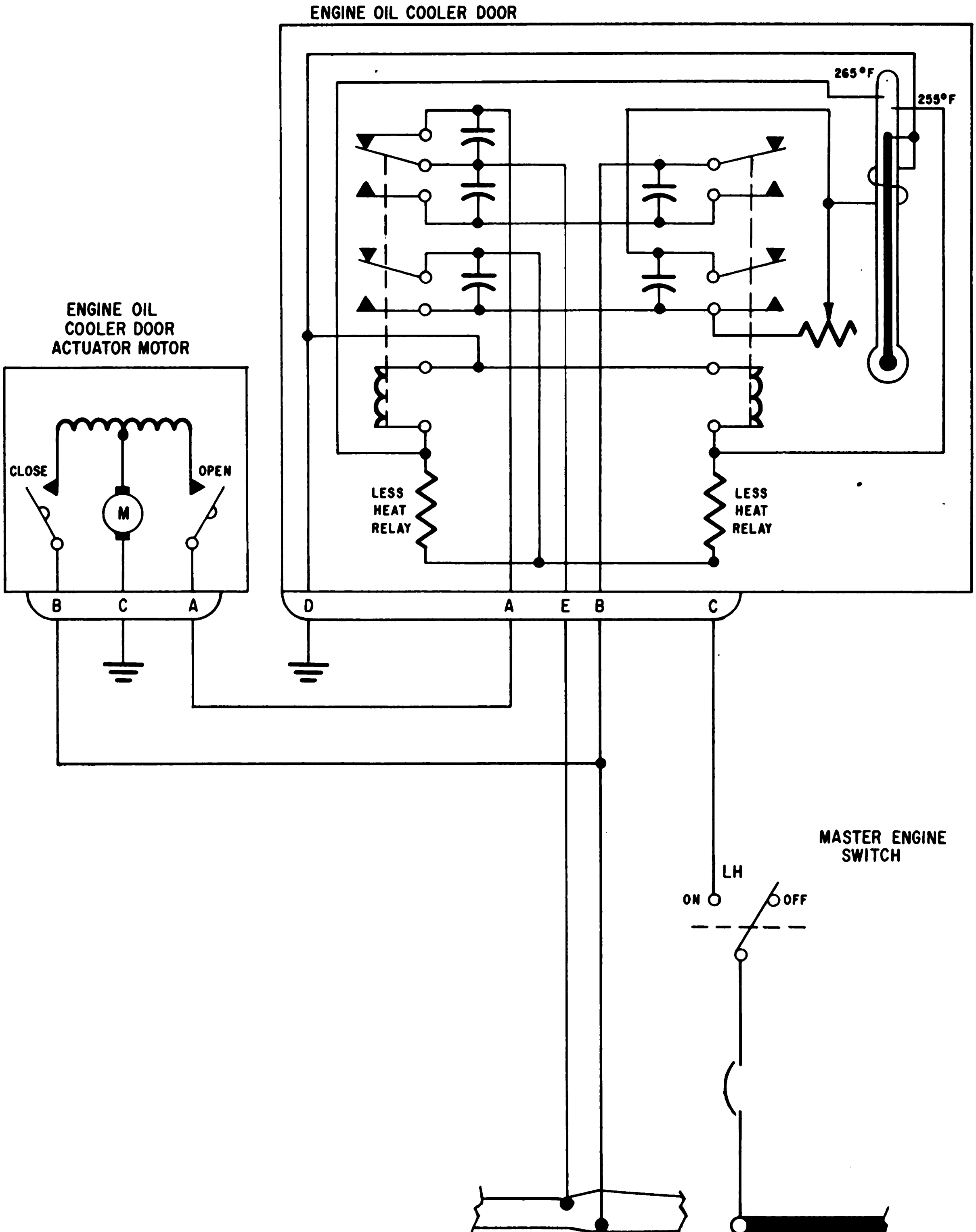


Figure 16-14.—Automatic oil temperature control circuit.

nozzle area to be increased sufficiently to reduce engine temperature to the reference temperature value. When engine temperature falls below the reference temperature, a nozzle area reducing signal is supplied to the actuator servomotor. Servomotor action then causes nozzle area to be reduced until engine temperature again equals the reference temperature, or until mechanical limits prevent further area reduction.

System Operation

The following system operation description is limited to operation of the temperature control portion of the nozzle control system. Descriptions of the hydromechanical control are limited to control response to temperature system signals.

Engine jet nozzle area is mechanically scheduled by the hydromechanical jet nozzle actuator according to pilot's power lever angle. The schedule provides a progressively reduced nozzle area as the power lever is advanced. In the military and afterburning ranges of power lever travel, exhaust nozzle area is scheduled fully closed.

The nature of electronic control output supplied to drive the jet nozzle actuator servomotor is determined by engine speed. Below a preselected speed, temperature control system operation holds the jet nozzle actuator in position for mechanical scheduling of nozzle area. Above this preselected speed, the temperature control system modulates nozzle area as necessary to prevent engine overtemperatures.

An engine speed switch controls power supplied to the speed relay in the electronic control. After the engine has accelerated to a preselected speed, the speed switch opens and deenergizes the speed relay. Opening of the speed relay switches jet nozzle area from a mechanically scheduled area value to a temperature modulated value.

So long as the speed relay of the electronic control is energized, a small under-temperature signal is supplied to the actuator servomotor. This voltage holds the servomotor against a mechanical stop in the actuator. When the servomotor is held against this stop, only mechanical scheduling of engine jet nozzle area can occur.

When the speed relay is deenergized, the small under-temperature signal is replaced by a voltage established in response to sensed engine temperature. This second voltage drives the servomotor to cause any required temperature corrections in engine jet nozzle area.

Engine temperatures are sensed by chromel-alumel thermocouples installed in the engine turbine outlet. This thermocouple sensed temperature is compared to the reference temperature of the electronic control. Any difference between the engine and reference temperatures causes an error signal to occur in electronic control input and amplifying circuitry. Magnitude of this error signal is determined by the difference between engine and reference temperatures. This error signal is applied to control variable phase voltage output of the electronic control.

Outputs of the electronic control are fixed and variable phase a-c voltages supplied to the actuator servomotor.

NOTE: The actuator servomotor case houses both a 2-phase induction motor and an induction generator. The motor and generator rotors are mounted on a unit shaft which rotates on bearings in the case end bells.

Two different fixed phase voltages are supplied for excitation of the actuator motor and generator. Generator excitation voltage is line voltage supplied through the electronic control to generator excitation windings. Motor excitation voltage is supplied from a tap on the primary winding of the electronic control power transformer. This motor excitation voltage is displaced by a capacitor to lead the voltage by approximately 90°.

Variable phase voltage is the a-c output voltage resulting from any error between the reference temperature and sensed engine temperature. Voltage is variable in both phase and magnitude. The voltage is in-phase with line voltage when an engine overtemperature is sensed by the electronic control. The relationship of variable phase voltage to fixed phase motor excitation is illustrated in figure 16-15. Magnitude of the variable phase voltage is determined by the amount of temperature error in reference and amplifying circuitry.

If an engine overtemperature exists during the transition from mechanical scheduling to temperature modulating, premature opening of the engine jet nozzle will occur. The resulting reduced pressure on the turbine will, in turn, tend to cause engine overspeeding. This premature nozzle opening is temporarily prevented by a false under-temperature signal injected

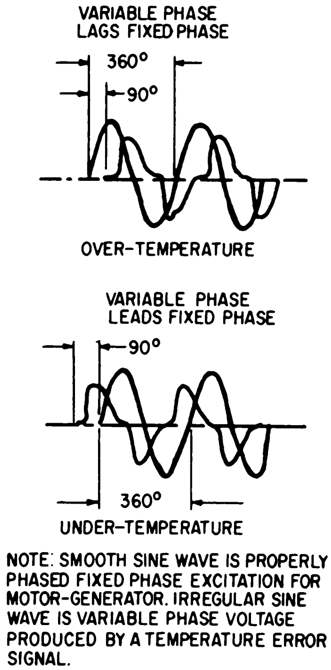


Figure 16-15.—Phase relationship of fixed and variable phase output voltages.

into electronic control circuitry. The signal is produced by a capacitor within the electronic control.

The capacitor producing voltage for the under-temperature signal discharges when the electronic control speed relay is deenergized. The capacitor discharged voltage is modulated and injected into electronic control amplifying circuitry.

In electronic control amplifying circuitry, the capacitor discharged voltage appears as an under-temperature signal. The under-temperature signal is of sufficient magnitude to override any overtemperature inputs to the electronic control. Resulting electronic control variable phase output holds exhaust nozzle area on the mechanical schedule to allow normal engine acceleration.

Electronic control circuitry incorporates an auxiliary reference temperature used to aid jet nozzle opening when afterburning is initiated. This auxiliary reference temperature is selected as a function of engine speed. The auxiliary reference temperature is normally effective only during the extremely short duration of time required for afterburner ignition. Temperature value of the auxiliary reference is less than the normal reference temperature of the electronic control.

Selection of the auxiliary reference temperature is accomplished automatically by engine and aircraft switches. The switching cycle causes the auxiliary reference to become effective at the instant of afterburner light-off. The normal reference temperature becomes effective again when engine speed reaches 100 percent.

While the auxiliary reference temperature is effective, engine temperature is compared to a temperature value lower than the normal reference. Thus, the electronic control sees an overtemperature even though the engine is operating on-temperature. Temperature control system response to this overtemperature is to cause rapid opening of the engine jet nozzle. This rapid opening of the jet nozzle reduces pressure on the engine turbine to permit more rapid engine acceleration.

If, during afterburning operation, engine speed drops below the speed required for afterburner ignition, an engine speed recovery system is actuated. This recovery system includes reinstating the auxiliary reference temperature. In this manner the temperature control system again drives the jet nozzle to the fully open position. The normal reference temperature becomes effective again after engine speed returns to 100 percent.

Rapid jet nozzle closing after completion of an afterburning cycle is aided by injecting a second false under-temperature signal into electronic control circuitry. Rapid nozzle closing is desired to prevent engine overspeeding and loss of thrust at the end of the afterburning cycle. This second false under-temperature signal is also produced by a capacitor discharging into electronic control circuitry.

The capacitor producing this second under-temperature signal discharges when the afterburning system arming switch is opened while retarding the throttle from the afterburning regime. The capacitor discharged voltage is modulated and injected into amplifying circuitry.

The under-temperature signal produced by the capacitor discharge voltage is added to the under-temperature sensed by engine thermocouples. The resulting large magnitude under-temperature signal causes rapid closing of the engine jet nozzle. This rapid nozzle closing

prevents a loss of pressure on the turbine and attendant engine overspeeding and loss of thrust.

Two voltage feedbacks are supplied to the electronic control whenever engine jet nozzle area is changing. Within the electronic control these voltage feedbacks become the generator damping and area rate signals. Both signals are mixed with the error signal in electronic control amplifying circuitry. And, both signals are degenerative to reduce magnitude of the error signal.

The generator damping signal is an a-c voltage supplied from the generator mounted on the unit shaft of the actuator motor-generator. Magnitude of this voltage is proportional to servomotor rotational speed. Phase of the voltage, referenced to fixed phase generator excitation, is determined by the direction of rotation.

The area rate damping signal is derived from d-c voltage feedback to the electronic control from an engine mounted potentiometer. The wiper of this engine potentiometer is positioned by exhaust nozzle shroud movement. Changes in the d-c voltage feedback occurring when the nozzle shroud moves are converted into a square wave a-c voltage within the electronic control. Amplitude of this a-c voltage is proportional to the rate of nozzle shroud movement, and thus to the rate of exhaust nozzle area change.

Effect of the generator damping and area rate signals is to reduce error signal magnitude as a temperature corrected exhaust nozzle area is being approached. Reducing magnitude of the error signal causes a corresponding reduction of variable phase voltage supplied to the actuator servomotor, and a reduction in motor rotational speed. These combined damping techniques permit high motor starting torques to meet system requirements while also providing system stability.

Circuit Operation

An understanding of Model EA-D5 electronic control amplifier circuitry is aided by an understanding of the relationships of individual circuits. This relationship is illustrated in block form, in figure 16-16. Briefly, the individual circuits and their functions include the following:

The temperature reference and chopper circuit ((1) of fig. 16-16), in which engine temperature is compared to a desired temperature. This temperature is either the reference temperature of the electronic control or the auxiliary reference temperature, depending on the engine operating mode.

The a-c amplifier and damping mixing circuit (2), in which any error between actual and desired engine temperatures is amplified. Damping feedback from the nozzle actuator motor-generator is also mixed with the error signal in this circuit.

The area rate damping circuit (3), in which d-c feedback from the engine exhaust nozzle is modulated and injected into the a-c amplifier. The modulating portion of this circuit is also used to inject capacitor discharged voltages into amplifying circuitry.

The demodulator and output circuit (4), in which the amplified and damped error signal is rectified and applied to control voltage supplied to drive the actuator servomotor.

The capacitor discharge circuits (5), which supply voltages for false under-temperature signals when required due to engine operating conditions. The d-c voltages discharged by the capacitors are converted into a form useable in a-c amplifying circuitry by the modulating portion of the area rate circuit.

Temperature Reference and Chopper Circuit

When the engine is operating, engine thermocouples supply a millivoltage reflecting engine temperature to the temperature reference circuit (fig. 16-17) of the electronic control. This millivoltage is compared to a compensated reference millivoltage (temperature) established in the temperature reference circuit. Reference millivoltage compensation consists of adjusting this millivoltage for changes in ambient temperature around the thermocouple cold junction. (The engine thermocouple circuit cold junction is located in the reference circuit.)

When thermocouple generated millivoltage is exactly equal to the reference millivoltage, a null condition exists in the reference circuit. Output of the reference circuit to a-c amplifying circuitry is at a minimum.

When thermocouple millivoltage is either greater or less than the reference millivoltage, an error condition occurs in the reference circuit. This error signal appears across input transformer T1. Polarity of the d-c error signal depends on whether thermocouple generated millivoltage is greater or less than the reference millivoltage. Amplitude of the error

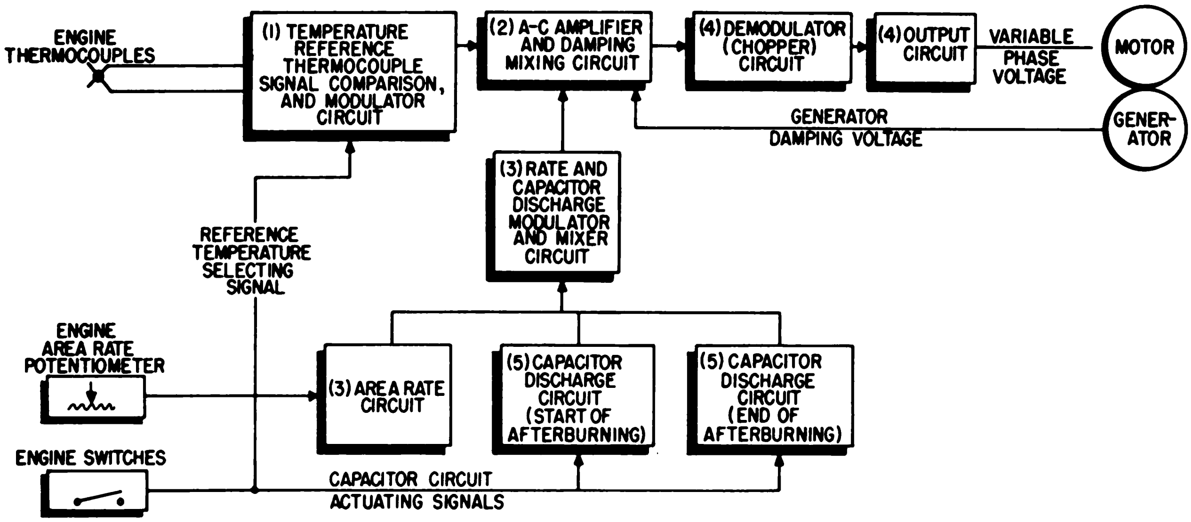


Figure 16-16.—Block diagram of Model EA-D5 electronic control amplifier.

signal is determined by the amount thermocouple millivoltage varies from the reference millivoltage.

Reference millivoltage compensation is accomplished with a temperature sensitive compensating resistor assembly (R8). This resistance assembly has a negative temperature coefficient. That is, resistance of the assembly varies inversely to its temperature. The assembly is physically located adjacent to the thermocouple circuit cold junction.

As ambient temperature at the thermocouple cold junction and R8 increases, thermocouple output millivoltage is reduced. This millivoltage reduction is equal to the reduced temperature difference between the thermocouple hot and cold junctions. Simultaneously, the resistance of R8 is reduced.

The reduced resistance of R8 results in a reduced voltage drop across R8. The voltage drop reduction is sufficient to compensate the reference millivoltage for the thermocouple millivoltage reduction caused by increased cold junction temperature.

Any d-c error signal in temperature reference circuity is fed to a-c amplifying circuitry through chopper K1 and input transformer T1. Chopper K1 is a switching device, and is driven by a 400-cps voltage. The d-c error signal is thus switched at power supply frequency and supplied to the primary winding of input transformer T1.

The primary winding of input transformer T1 is center tapped. This center tap is connected to the chromel (positive) thermocouple lead to complete one side of the input circuit to the electronic control. Each end of the primary winding is connected to a fixed contact of chopper K1. Any error between engine and reference temperatures is supplied to the reed of chopper K1. Thus, any error signal is alternately supplied through K1 to either end of the primary winding of T1. When an error signal for an engine overtemperature occurs, each end of the primary winding of T1 is alternately made negative with respect to the center tap. Conversely, each end of the primary becomes positive with respect to the center tap when an engine under-temperature occurs.

The switched, or chopped, error signal appears as a square wave alternating voltage on the secondary of T1. Phase of the a-c secondary voltage, referenced to line voltage, depends on polarity of the modulated error signal in the primary winding.

Potentiometers R6 and R9 are adjusted during electronic control calibration to establish the normal and auxiliary reference temperatures of the control. Selection of either the normal or auxiliary reference temperature is accomplished by temperature reset relay K5. When K5 is deenergized, the circuit to the wiper of normal reference temperature adjusting potentiometer R6 is completed. When the relay

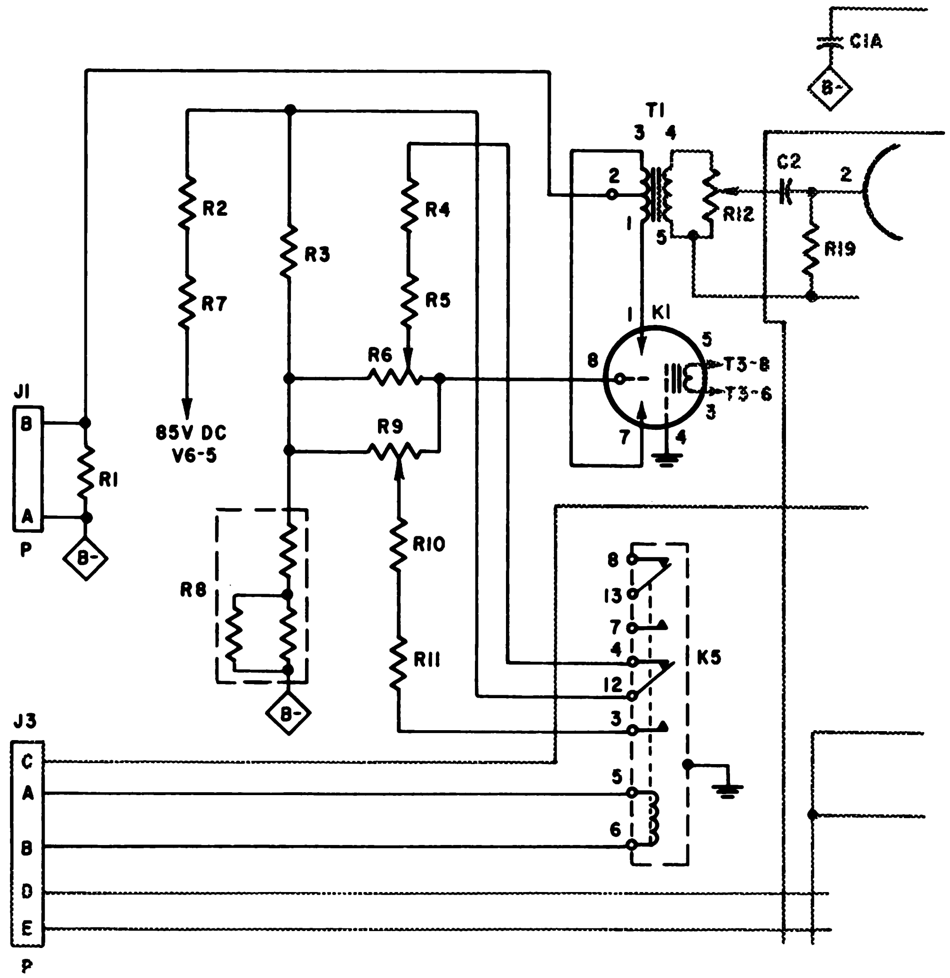


Figure 16-17.—Temperature reference and chopper circuit.

is energized, the circuit to the wiper of auxiliary reference temperature potentiometer R9 is completed. Power for operation of relay K5 is controlled by engine and aircraft switches.

ARMAMENT CIRCUITS

Armament circuits in an aircraft that are of interest to the aviation electrician are those circuits which deliver electrical power to various armament devices, such as the bomb, rocket, missile, gunnery, and photographic systems. In most aircraft this equipment receives its d-c power from an armament bus; this bus in turn receives its power from the secondary d-c bus through various control circuits. A-c power is supplied from one phase of the a-c secondary bus.

Aircraft bombs, torpedoes, rockets, mines, missiles, and fuel or chemical tanks are suspended either internally or externally from the aircraft. Bomb racks, shackles, and combination bomb racks and rocket launchers are devices whose function is to carry, arm, and release these stores. The racks are usually bolted to the wings or fuselage, or placed in the bomb bay of the aircraft. Shackles are generally suspended from internal guide rails by utilizing pivoting supports. Normally, the bomb rack has its own arming and releasing unit integral with the rack. These units are operated remotely by electrical impulse or a manual release. Shackles are usually dependent on an attached unit, or units, to arm and release their stores.

Refinements to suspension, arming, and releasing devices for aircraft have brought about development of associated electric equipment, such as intervalometers to time the release of bombs. There are other units which preselect the desired arming of bomb fuzes, and establish definite order and grouping of rockets fired. Each serves a definite purpose in accurately delivering stores.

GUNS AND GUN CAMERAS

The Navy is currently replacing the guns carried internally aboard aircraft with gun pods which are externally carried. However, the firing of either internal or external guns is very similar. A typical gun and camera firing circuit is discussed in the following paragraphs.

Guns

The majority of gun electrical systems utilize both a-c and d-c circuits in their operation. (See fig. 16-18.) The d-c power is used to control the functions of the gun system, cameras, and ammunition booster operation. A-c power operates transformers or other components of the system to supply power to the firing circuits.

The d-c power is furnished by the secondary d-c bus (1 of fig. 16-18), while the two a-c circuits are supplied by a secondary a-c bus (2). Note that each circuit is protected by its own circuit breaker and is controlled by power from the armament bus (3). The one exception to this is the camera test circuit, which is not controlled by the armament bus power. This makes it possible to test the camera without recourse to any other armament circuit.

Since the armament bus supplies control and gun charging power, it must be energized before the other circuits can be operated. The armament bus (3) is connected to the d-c secondary bus (1) through a circuit breaker (4) and the normally open master armament relay (5). The control circuit for this relay is routed from the secondary d-c bus to the solenoid coil of the relay, through a circuit breaker (4), master armament switch (6), and either of two sets of contacts in the separately controlled landing gear relay (7).

The path the current will take from this relay depends on the position of the landing gear and/or in some installations the tailhook control handle (8). With this handle in the UP position the Micro switch (9) is closed, which energizes the landing gear relay and closes the UP contacts. This completes the circuit to the master armament relay, which energizes the armament bus. With the landing gear handle in the DOWN position, the landing gear relay is deenergized and the DOWN contacts are closed. The circuit current is then routed to the normally open armament safety disabling relay (10) and armament disabling switch (11). Closing the switch momentarily causes the relay to close, completing separate circuits to both its own and the master armament relay solenoid coils, energizing the armament bus. Once closed, the armament safety disabling relay will remain closed until power to it is interrupted, even after the armament disabling switch is open. The armament safety disabling circuit is the only safe means of energizing the armament system when the landing gear is in the down position.

Gun Charging Circuit

With the exception of the master armament, gun charging, and camera test circuits, all circuits are controlled through the trigger switch (12). The gun charging valve (13) is connected to the armament bus through a circuit breaker and one side of the guns READY/SAFE switch (14). The guns may be charged (providing the circuit breaker is closed) by placing the READY/SAFE switch on SAFE. The gun charging circuit is fed from the armament bus for reasons of safety. When power to the armament bus is interrupted, the charging valve will deenergize, and return the guns to safe, regardless of the position of the READY/SAFE switch.

Camera Circuit

Power for the camera(s) (15) is taken from the secondary d-c bus and fed through a circuit breaker, a normally open relay (16), and a TEST/RUN switch (17). The test side of the TEST/RUN switch is connected to the circuit ahead of the relay. Placing the switch to the TEST position bypasses the relay and supplies current directly to the camera(s). When released, the switch will return to the RUN position. The open relay now prevents the camera(s) from running until the trigger (12) is pulled.

Nomenclature for figure 16-18.

1. Secondary d-c bus.
2. Secondary a-c bus.
3. Armament bus.
4. Circuit breakers.
5. Master armament relay.
6. Master armament switch.
7. Landing gear relay.
8. Landing gear/tailhook control handle.
9. Microswitch.
10. Armament safety disabling relay.
11. Armament safety disabling switch.
12. Trigger switch.
13. Gun charging valve.
14. Guns READY/SAFE switch.
15. Camera(s).
16. Camera isolating relay.
17. Camera TEST/RUN switch.
18. Gun vent doors.
19. Vent doors control valve.
20. Armament selector switch.
21. Gunfiring relay.
22. Guns.
23. Vent door switches.
24. Gunfiring interlock control.
25. Gun interlock relay.
26. Interlock bypass relay.
27. Current limiting resistors interlock bypass firing circuit.
28. Low value shunting resistor.
29. Feeder switch.
30. Interlock bypass relay coil.
31. Current limiting resistor normal firing circuit.

Gun Vent Door Circuit

The gun vent doors (18) are controlled by the camera relay (16). The vent doors control valve (19) is connected to the secondary bus through a circuit breaker, the armament selector switch (20) (guns position), and the previously mentioned relay (16), which is controlled directly by the first position of the two position trigger switch (12). The second position of the trigger controls the gunfiring relay (21) through the armament selector and guns READY/SAFE switches. The gunfiring relay controls two (normal) firing circuits (one circuit for each pair of guns), the interlock bypass firing circuit, and an alternate circuit to the vent doors control valve. The latter insures that the vent doors will open in the event of a malfunction of the normal operating circuit. To prevent dangerous accumulation of gas in the gun bays, the guns are prevented from firing until the vent doors are open. This is accomplished by the vent door position switches (23) in the firing circuits. These switches are closed by the vent doors opening and opened by closing the vent doors.

Firing Circuit

To fire electrically primed ammunition efficiently, a higher voltage than is supplied by the aircraft generators is required. The required voltage (250-300 volts d.c. or pulsating d.c.) is developed within a power supply. This may be a transformer unit for each gun or an interlock control which supplies all guns through a circuit for each pair of guns. The power supplies require an input of 115 volts a.c. The gunfire interlock control (24) is connected to the a-c secondary bus through a circuit breaker and relay (25). Closing the trigger circuit breaker supplies power to close the relay (25), completing the input circuit to the interlock control.

NORMAL FIRING CIRCUITS.—The electrical system contains two parallel normal firing circuits, and each circuit supplies power to a pair of guns. Since the normal firing circuits are identical, only the circuit controlling one left-hand gun (22B) is discussed in detail.

In normal firing, the gun receives its electrical energy from the gunfiring relay (21), through the limiting resistor (31), via the shunting resistor (28), and the normally closed contacts of the interlock bypass relay (26A). It continues by a route passing through the open LH vent door relay (23), and finally through the feeder switch (29) to the LH gun (22B), firing the gun. Should any part of the branch circuit between the resistor and the gun short out, current to the short is limited, allowing the other branches to continue to function.

INTERLOCK BYPASS FIRING CIRCUIT.—During normal firing, a shorted round may be fed to the gun. When this occurs the interlock bypass firing circuit is connected to the gun allowing 115-volts a.c. to be applied to the gun to fire or burn out the round.

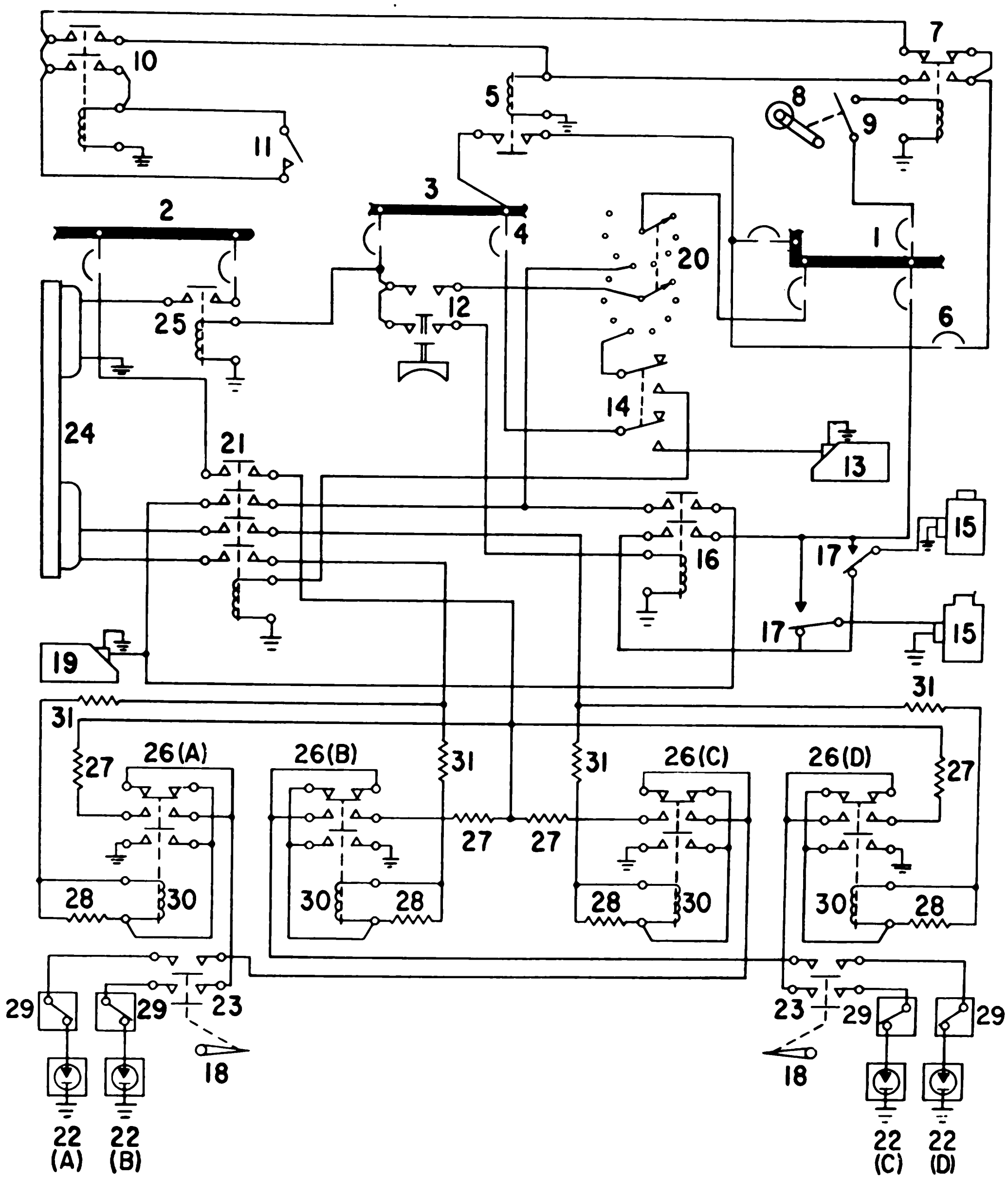


Figure 16-18.—Gunnery electrical schematic.

The interlock bypass circuit functions in the following manner: The interlock bypass firing circuit is connected to one set of normally open contacts in each interlock bypass relay (26). The other set of normally open contacts is used to ground the normal firing circuit when the relay is energized (closed).

A shorted round causes excessive current to be drawn through a resistor (28), actuating the interlock bypass relay (26A). The voltage drop across this resistor (in direct proportion to the current) is in parallel with the solenoid coil (30), causing the coil to be energized, which closes the normally open relay (26A). When the relay is closed, the Sec a-c bus (2) is connected directly to the gun by way of the gunfiring relay, resistor (27), interlock bypass relay (26A), the vent door switch (23), and the feeder switch (29).

The normal firing circuit is connected during this time to ground through the relay (26A). The relay solenoid (30) holds the gunfiring relay closed until power to the relay is interrupted. Once the trigger is released the relay will return to the normal fire position. It may be noted that each branch of the bypass circuit passes through a current limiting resistor (27). These serve the same function as the current limiting resistors in the normal firing circuit.

SYSTEM OPERATION.—Assume that the system is setup in preparation to fire as follows:

1. All buses energized.
2. All circuit breakers in.
3. Armament selector switch on GUNS.
4. READY/SAFE switch on READY.

Closing the trigger switch to the first position, closes the camera isolating relay (16), which starts the camera(s) (15) and opens the vent doors (18). As the doors open, they close the vent door position switches (23) in the firing circuit. Further pressure on the trigger closes the second position contacts, completing the circuit from the trigger (12) through the armament selector (20) and READY/SAFE switch (14) to close the gunfiring relay (21). Closing the gunfiring relay completes the three circuits to the interlock bypass relay, assuming the system is operating normally. The firing circuits pass through the normally closed contacts of the relays, the closed vent door position switches, and feeder switches to fire the guns. The interlock bypass firing circuit uses the same circuit from the interlock bypass relays to the guns, but is energized only when the relay is closed by a shorted round.

Gunfiring Power Supplies

The two basic types of gunfiring power supplies most commonly used in conjunction with electrically primed ammunition are the gunfiring interlock control, and the transformer or transformer-rectifier. Power supplies of either type requires an input of 115-volts a.c. for operation.

GUNFIRING INTERLOCK CONTROL.—The interlock control develops a d-c pulsating firing voltage which is supplied to the two firing circuits (one for each pair of guns). Since only one circuit receives a positive pulse at any given instant, only one pair of guns may fire at any instant; this serves to reduce vibration from the firing of guns.

The output of the interlock control, when measured with a d-c meter, will indicate only 32 ± 3 volts, though the peak output is 370 volts. The low reading is obtained because d-c voltmeters read only the mean voltage. For example, a pulsating circuit delivering a square wave pulse of 100 volts for 50 percent of the time and zero volts for the remaining 50 percent will have a mean output voltage of approximately 50 volts d.c. The gunfiring interlock control is a single unit designed to operate on 115 volts a.c. and delivers a pulsating d-c square-wave output to the firing circuits of the guns.

The various potentials for the operation of the multivibrator and amplifiers (fig. 16-19) are developed within the power supply. The outputs from the multivibrator (a square-wave generator with two outputs that are 180° out of phase) are fed to separate amplifiers. Each is amplified by two stages of amplification and fed to the gun firing circuit previously discussed.

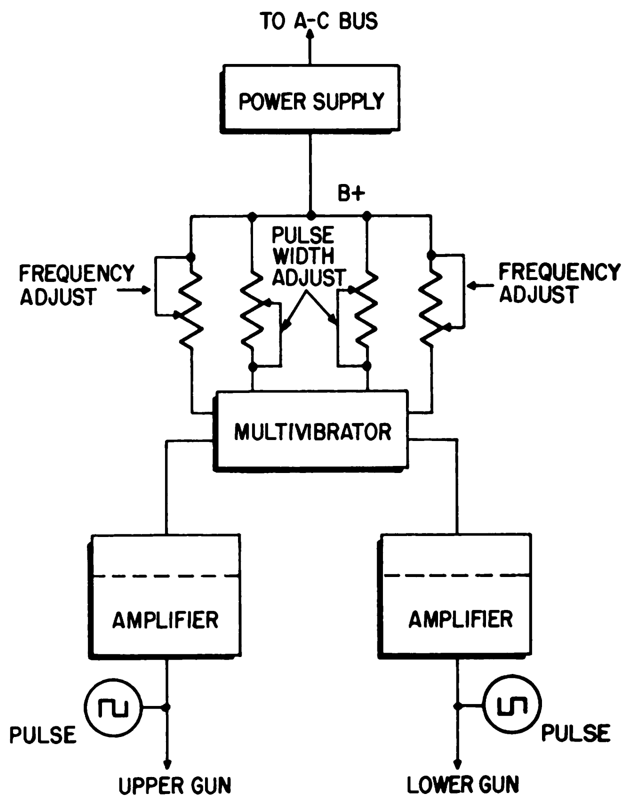


Figure 16-19.—Gun firing interlock control block diagram.

A detailed explanation of amplifiers and multivibrators may be found in Basic Electronics, NavPers 10087-A and should be studied.

The interlock control is repairable in the field and is adjustable in pulse width and frequency. Troubleshooting and repair may require some bench test equipment and should be undertaken only by personnel who are familiar with electronic equipment. Before attempting repairs, reference should be made to the proper Maintenance Instructions Manual, or other appropriate publications.

TRANSFORMER POWER SUPPLIES.—Several variations of transformer power supplies are used to supply firing voltage to the guns. Some systems may use a simple voltage booster transformer, firing the guns with the unrectified output of the transformer which is fed through a current limiting resistor. Other systems utilize bridge networks to rectify the transformer output and feed the resultant d-c voltage through current limiting resistors and control relay. Since this latter type system usually contains the most components found in the simpler system, it is discussed in detail.

The transformer-rectifier power supply consists of one or more sealed plug-in units for each gun. The firing circuit for each gun consists of a power supply unit (fig. 16-20 (A)) and a control circuit unit (fig. 16-20 (B)).

The power supply unit (fig. 16-20 (A)) consists of a transformer and a bridge rectifier circuit. Its function is to transform the 115-volt a-c input into an output of approximately 250-300 volts. This output is rectified by the bridge rectifier producing a d-c output of approximately the same voltage and is fed to the control circuit.

The control circuit contains a current limiting resistor and control relay (fig. 16-20). A capacitor is connected between the relay input contact and ground to prevent arcing when the relay is opened or closed. It should be noted that the output of the gun firing circuit is supplied to the gun through a feeder switch.

Since the plug-in units of the transformer-rectifier power supplies are sealed, they are not normally repairable in the field. However, detailed information on part arrangement may be found in the applicable manual.

RELEASE SYSTEM

The multiple weapons release system contains five major components and panel assemblies as follows:

1. The intervalometer.
2. No. 1 circuit breaker panel.
3. No. 2 circuit breaker panel.
4. Weapons control panel.
5. Multiple weapons relay panel.

The intervalometer is used to provide controlled 28 v d-c pulses to the armament stations. These pulses are applied alternately at two separate output terminals. One output terminal is connected to the left armament stations, the other output terminal is connected to the right armament stations. In the single or pairs mode the width of the pulse depends upon the length of time the stores release switch is depressed. In the ripple and cluster modes, a series of pulses 25 milliseconds (accurate within +8 to -2 milliseconds) width are fed to the armament stations. These controlled pulses supply the bomb release signal. The No. 1 and No. 2 circuit breaker panels supply the voltage

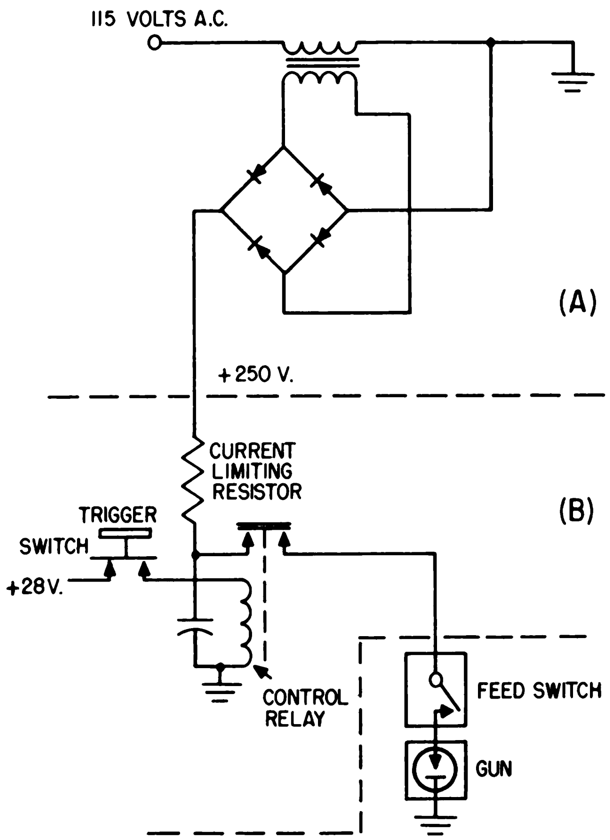


Figure 16-20.—Power Supply. (A) Gun power supply; (B) gunfiring control circuit.

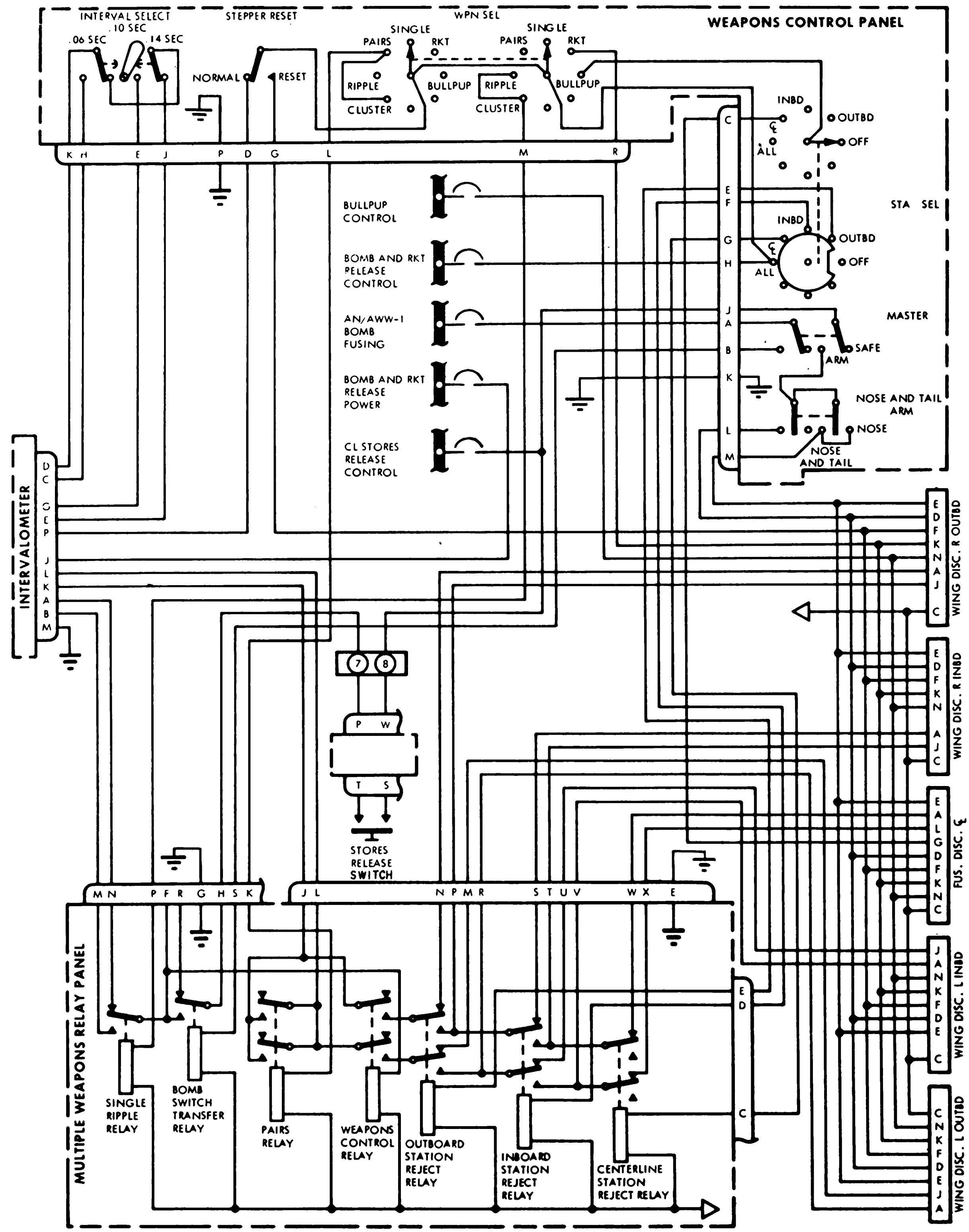


Figure 16-21. —Release system schematic.

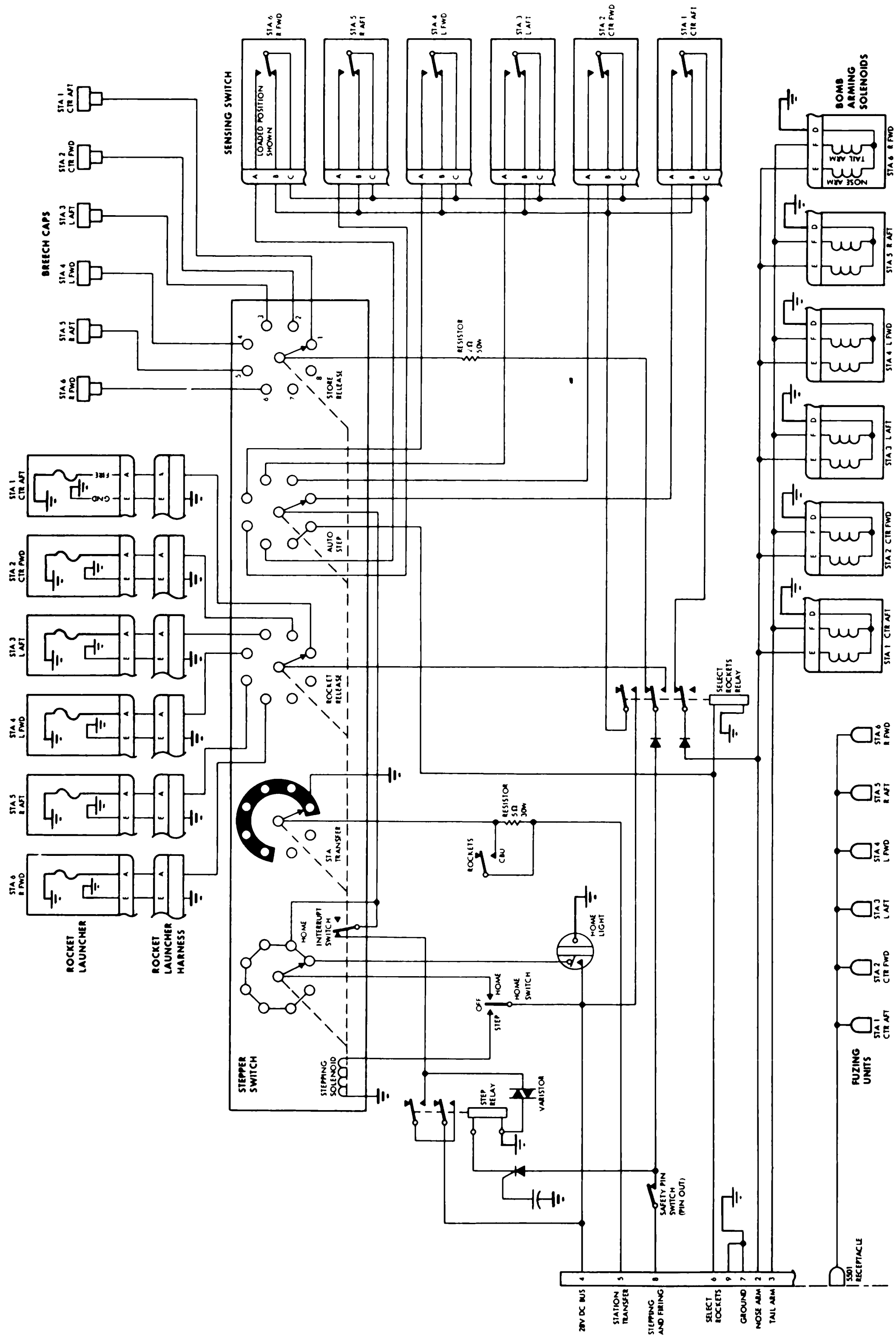


Figure 16-22.—Multiple ejector rack schematic.

for the operation of all release circuits. The weapons control panel contains switches for all the selection of weapon, station, interval of release, and arming of stores. The multiple weapons relay panel contains 10 relays of which 7 are used in the multiple weapons system. These relays route the bomb release signal to the proper armament station. (See fig. 16-21 for the schematic of the release system.)

System Operation

The intervalometer receives 28 v d.c. for operation from the bomb and rocket release circuit breaker. The STA SEL and WPN SEL switches receive voltage from the bomb and rocket control circuit breakers. The station reject relays, outboard station reject, inboard station reject, and centerline station reject are normally energized by voltage from the STA SEL switch.

When the pilot selects a station, that station's reject relay is deenergized. With the stores release switch depressed, 28 v d.c. is sent through the normally open contacts of the bomb button transfer relay and the normally open contacts of the single ripple relay as the intervalometer initiates the signal. The intervalometer returns the voltage through the appropriate station reject relay to the selected armament station. If the pilot selected PAIRS or CLUSTER on the WPN SEL switch, the intervalometer return signal will be split at the pairs relay, then sent to the station reject relay. This dual signal will release a bomb from the right and left armament station or, in the case of the centerline, it will release two bombs from the centerline armament station.

MULTIPLE AND TRIPLE EJECTOR RACKS

The basic mechanical components and electrical systems are the same in both the multiple and triple ejector racks. The main difference between the two units is the number of stations—six stations for the multiple ejector rack while the triple ejector rack has three stations.

Operation for the multiple ejector rack (fig. 16-22) is as follows:

Arming voltage for the nose and tail arming solenoids comes into the rack through connector pins 2 and 3. Pin 5 supplies a ground, from the station transfer wafer in the rack for the station transfer relay in the multiple weapons adapter. The pulse from the intervalometer enters through pin 8 and energizes the step relay for the width of the pulse. If bombs are the stores, this pulse is also sent through the normally closed contacts of the select rockets relay and to the bomb wafer of the step switch to release a bomb. If rockets are the stores, the pulse is sent through the normally open contacts of the select rockets relay to the rocket wafer of the step switch to fire a pod of rockets.

The select rockets relay is energized by 28 volts d.c., when WPN SEL switch is in the RKT DISP position. When the step relay is momentarily energized, 28 volts d.c. is sent through the normally closed contacts of the step relay. This voltage is then applied to the coil of the step switch, energizing it momentarily. As the step switch is deenergized, it steps all five wafers of the switch to the next position. If one or more stations are empty, 28 volts d.c. will be applied through the loading limit switches of the empty station to the coil of the step switch, causing the switch to step and thus bypassing the empty station.

CHAPTER 17

AIRCRAFT ELECTRIC-HYDRAULIC AND PNEUMATIC SYSTEMS

The word hydraulics was derived from the Greeks and originally covered a study of the physical behavior of water at rest and in motion. Today, hydraulics pertains to the science of engineering which deals with water or liquid in motion.

In our present day systems, oil is used in place of water. This is mainly due to the fact that water has a corrosive effect and oil does not. In current naval hydraulic systems, oil is almost invariably the hydraulic medium, since its lubricating qualities help to insure smooth positive operation for fastmoving parts.

If the system is well adapted to the work it is required to perform, it can provide smooth, flexible, uniform action without vibration, and be unaffected by variations of the load. The pressure in a hydraulic system must be controlled as well as the movement of the component fluids. This movement causes friction within the liquid itself and against the containing surfaces which, if excessive, can lead to serious losses in efficiency. It is necessary for the AE to understand how a hydraulic system functions, both in terms of the general principles common to all physical mechanics and the peculiarities of the particular system installed in the aircraft of his squadron. For a detailed study of hydraulic principles refer to Basic Hydraulics, NavPers 16193.

ELECTRIC-HYDRAULIC OPERATED VALVES

The electric-hydraulic operated valves used in current aircraft are of many types and perform various functions. Examples of systems in which they may be found are wingfold, landing gear, canopy, speed brakes, and nose gear steering.

Because of the wide variety of valves used, it would not be advantageous to attempt a discussion of all types. For this reason a four-way, three-position, dual solenoid selector valve as used in a speed brake system is discussed. Figure 17-1 is an operational schematic diagram of a speed brake system used in the F-4B aircraft.

SPEED BRAKE SYSTEM

Extension

The speed brakes are extended by placing the speed brake control switch (located on the throttle lever grip) to the OUT position (the OUT position is a momentary contact, spring-loaded to STOP). Holding the control switch in the OUT position energizes the selector valve extend solenoids (solenoids A and B), connecting utility hydraulic pressure to the extend side of the actuators and connecting the utility return to the retract side of the actuators. Any desired position of the brakes may be obtained and will be held by a "hydraulic lock" within the selector valve. The speed brake out warning light will illuminate when either the left or right speed brake is not fully retracted. The warning light circuit is completed through either the left or right speed brake retract position switch.

Retraction

The speed brakes can be retracted by moving the speed brake control switch to the IN position (this is a maintaining position and the switch must be manually returned to STOP). The IN position of the switch deenergizes both solenoids A and B in the selector valve and system flow is the reverse of the extend flow. The speed brake warning light will go out when both speed brakes are fully closed.

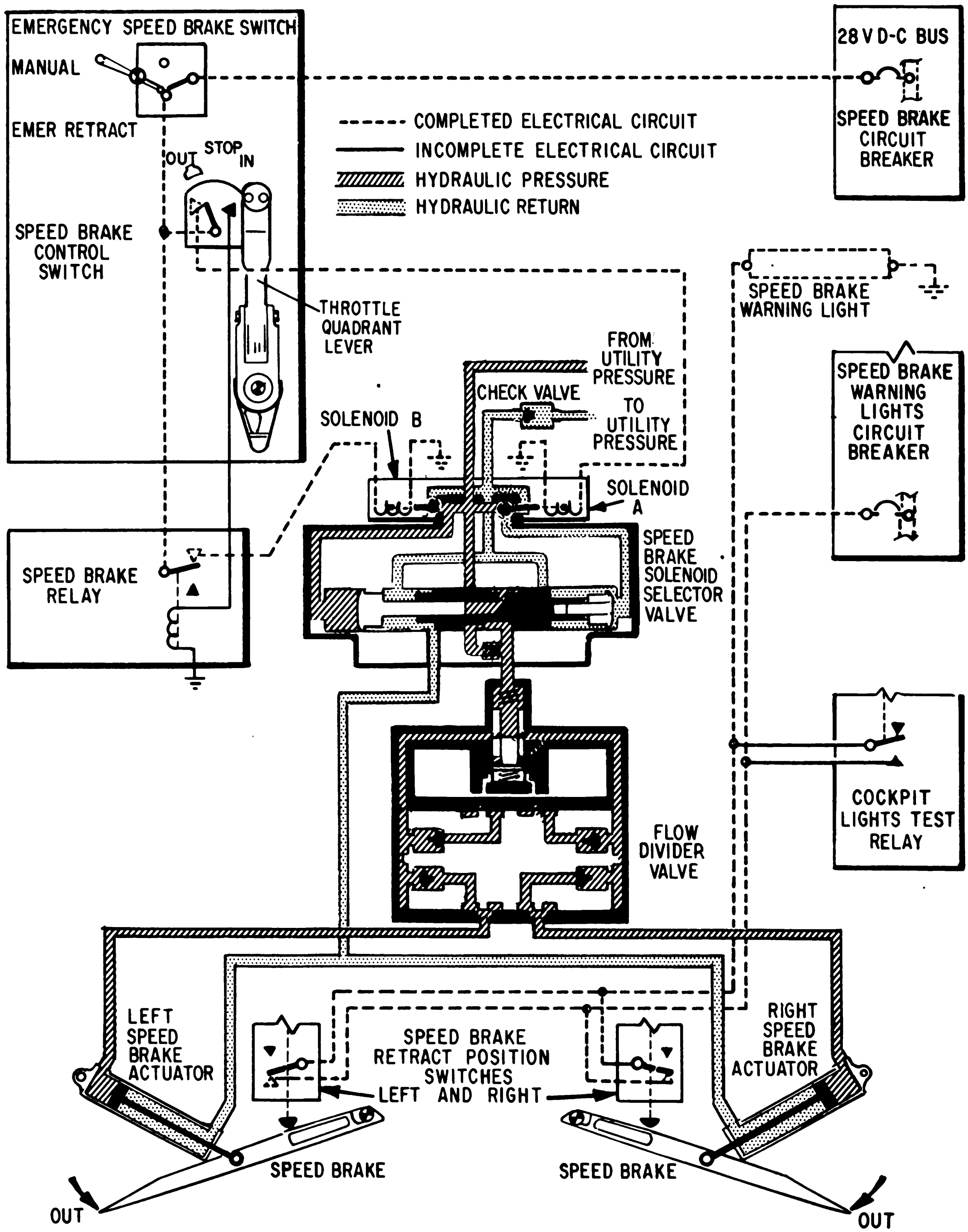


Figure 17-1.—Speed brake system schematic.

Emergency Retraction

The speed brakes can be retracted by placing the emergency speed brake switch in the EMER-RETRACT position. This switch deenergizes solenoids A and B of the selector valve which connects both the extend and retract sides of the speed brake actuators to the system return. This switch is necessary only if the speed brake relay does not energize when the speed brake control switch is placed in the IN position. If an electrical failure (popped circuit breaker) occurs with the speed brakes extended, the retraction would be the same as the actuation of the emergency retract switch. In the emergency condition stated above, the speed brakes are forced shut by the airstream.

Solenoid Valve Operation

The speed brake selector valve is a solenoid operated, four-way, three-position half-trail valve. A check valve, installed between the pressure inlet and port, provides pressure relief in the event the speed brakes are locked in the extend position at excessive speeds. The bobbin assemblies are individually actuated by solenoids A and B and control hydraulic pressure to the actuating pistons. The spool is controlled by the actuating pistons and may be positioned to "stop," "extend," or "retract."

EXTEND POSITION.—With both solenoids A and B energized, as shown in figure 17-2, both bobbin assemblies are moved to the left. Hydraulic pressure is directed to the actuating piston (1). Pistons (2) and (3) are open to return. Hydraulic pressure, behind piston (1) and in the center chamber of the spool drives the spool to the extend position. Pressure from the pressure inlet passes through the valve and out port (1) to the extend side of the speed brake actuating cylinders. Port (2), from the retract side of the cylinders, is open to return.

RETRACT POSITION.—With both solenoids A and B deenergized, as shown in figure 17-3, the bobbin assemblies are moved to the right. Hydraulic pressure is directed to the actuating pistons (2) and (3), and piston (1) is open to return. Pistons (2) and (3) drive the spool to the retract position. Port (1), from the extend side of the speed brake actuating cylinders, is open to return. Pressure from the pressure inlet passes through the valve and out port (2) to the retract side of the cylinders.

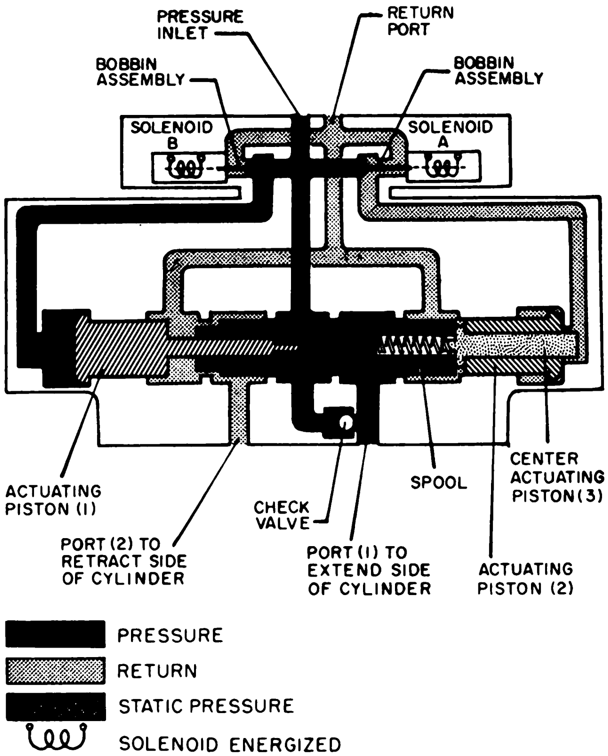


Figure 17-2.—Selector valve, extend position.

STOP POSITION.—With solenoid B energized and solenoid A deenergized as depicted in figure 17-4, the bobbin assemblies are moved outward directing hydraulic pressure to the three actuating pistons. The pistons move inward moving the spool to the center position. Ports (1) and (2) are closed preventing flow to or from the speed brake actuators thus hydraulically locking the speed brakes in their existing position. If excessive airloads exist on the speed brakes, the back pressure through port (1) exceeds a preset value, the check valve will unseat permitting fluid to flow from the extend side of the speed brake actuators back through the pressure port. The speed brakes will then retract to a point of pressure equilibrium.

NOTE: In remote cases where solenoid A is energized and solenoid B is deenergized, as shown in figure 17-5, the speed brakes will extend and remain extended as long as the control switch is in the OUT position. When the control switch is returned to the STOP position, the speed brakes will retract.

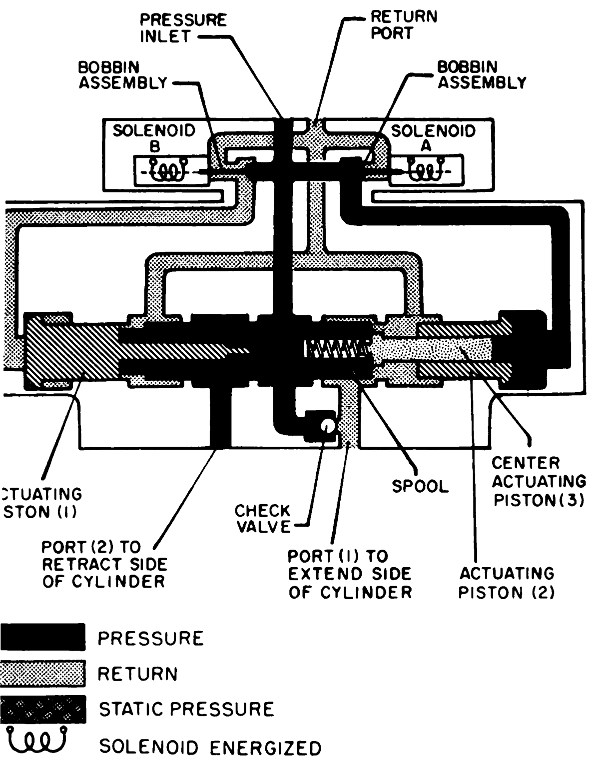


Figure 17-3.—Selector valve, retract position.

ANOPY SYSTEM

As previously stated, solenoid valves are sed in many applications in naval aircraft. The ydraulic system shown in figure 17-6 (canopy ystem for A-6A aircraft) is another illustration f a hydraulic electric system employing a sole- oid selector valve. The canopy selector valve s a four-way, two-position spool valve, which s actuated either electrically or manually.

The canopy system consists of a sliding anopy mounted over the cockpit area and the omponents required for normal operation and mergency jettison of the canopy. The entire ystem is hydraulically operated with the ex- eption of the electrical canopy jettison de- ice. Hydraulic power for operation of the anopy is furnished by the combined hydraulic ystem or the hand pump system.

When the canopy switch is in the CLOSE posi- on, a circuit is completed from the 28-volt d-c us through the control circuit breaker to a ter- inal on the isolation switch. Current then flows from the terminal, through the closed contacts of the canopy switch, to solenoid 2 of the canopy selector valve. The selector valve energizes to the close position and hydraulic pressure from either the combined hydraulic system or the hand pump system flows through the selector valve into the canopy close line. Pressure is delivered through a flow regulator to the rod end of the canopy actuating cylinder, causing the piston and rod to retract and close the canopy.

When the canopy switch is in the OPEN position, a circuit is completed from the 28-volt d-c bus through the control circuit breaker, the isolation switch terminal, through the opposite contacts of the canopy switch, to solenoid 1 of the canopy selector valve. The selector valve energizes to the open position, reversing the sequence of pressure and return flow. Hydraulic pressure flows through the canopy open line to the canopy seal valve and hydraulically trips the seal valve, dumping the air pressure in the canopy seal and allowing the seal to deflate. Pressure in the canopy open line continues its

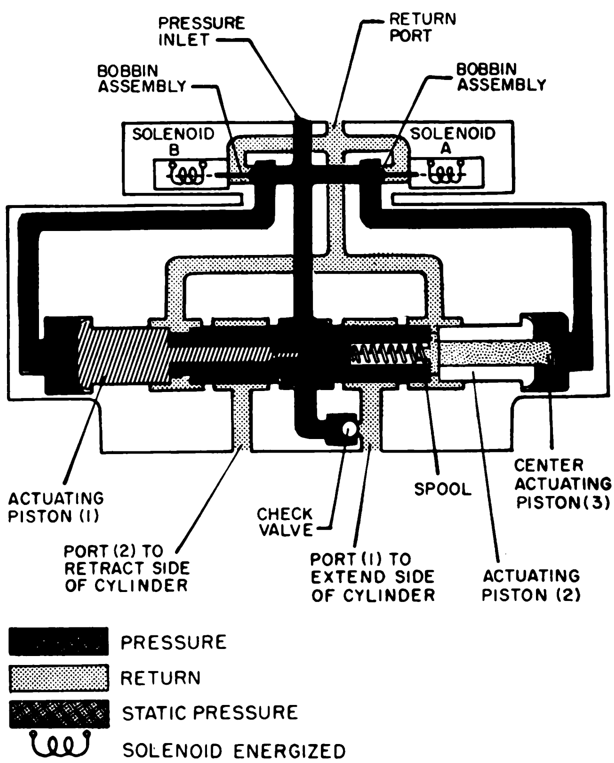


Figure 17-4.—Selector valve, stop position.

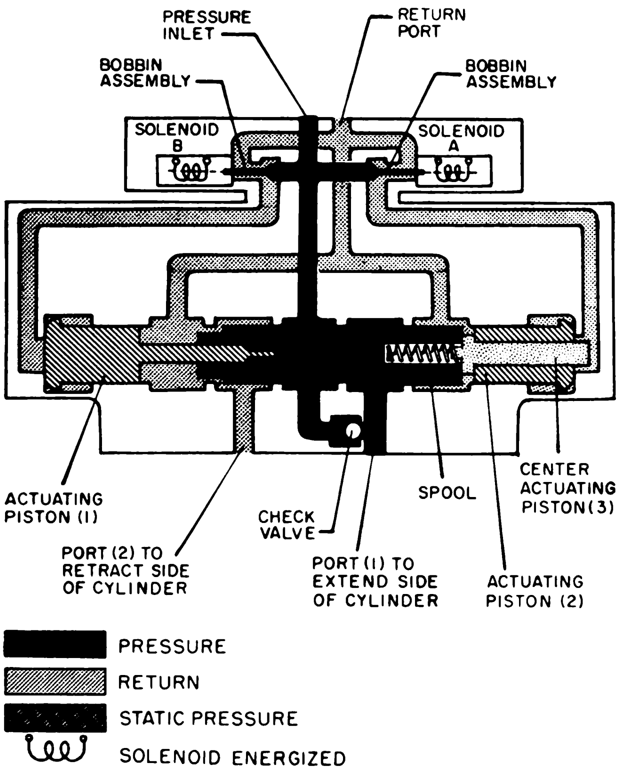


Figure 17-5.—Selector valve, solenoid A energized, solenoid B deenergized.

flow through a flow regulator to the backhead end of the cylinder; the pressure causes the cylinder to extend, opening the canopy. Hydraulic fluid in the opposite end of the cylinder is released through the canopy close line to the canopy selector valve, across the valve, and into the return flow line of the combined hydraulic system. Fluid is then returned to the main reservoir of the system.

For emergency jettison of the canopy (fig. 17-7), a circuit is completed from the battery to the emergency canopy jettison switch in the cockpit, and then to each of the two emergency outside jettison switches. Closing any of the three switches will complete the circuit direct to the electrically-fired canopy jettison cartridge on the backhead end of the canopy cylinder. The cartridge discharges through the canopy cylinder, causing the canopy to be jettisioned.

ROTODOME ROTATION SYSTEM

Another type of system that utilizes a solenoid operated valve is the rotodome rotation system such as employed on the E-2A aircraft. The rotodome systems rotate the rotodome and elevate and retract it to facilitate stowage of the aircraft below deck. These operations are performed by the rotodome rotation system and the rotodome elevation and retraction system. The rotodome rotation system shown in figure 17-8 functions as follows:

The rotodome rotation system operates in conjunction with a radar set control to rotate the rotodome at a constant speed of 6 rpm. The system uses pressure from the combined hydraulic power system to drive the rotodome rotation constant-speed motor. The rotodome rotation and support mechanism gearbox, to which the rotodome constant-speed motor is mounted, reduces the speed of the motor and transmits the motion to the rotodome shaft. The system is controlled by the ANT switch on the radar set control at the radar operator's station. For hydraulic maintenance, the antenna can be operated by the dome rotate and dome stop manual override buttons on the rotodome rotation selector valve. The system can be operated when the rotodome is in the retracted or elevated position.

Momentarily positioning the ANT switch to ON directs 28 volts d.c. from the right transformer-rectifier bus to pin A of the rotodome rotation selector valve to energize the dome rotate solenoid. The rotodome rotation selector valve directs 3,000-psi hydraulic pressure through the rotodome motor upper and aft swivels to the rotodome rotation constant-speed motor. The motor converts the hydraulic pressure to mechanical motion that is transmitted to the rotodome gearbox. The rotodome shaft is directly attached to the gearbox. The rotodome rotation constant-speed motor automatically maintains the rotodome shaft rotation at a constant speed of 6 rpm. Return hydraulic fluid from the rotodome rotation constant-speed motor is directed back through the rotodome motor aft and upper swivels through the motor return manifold to the hydraulic heat exchanger in the combined hydraulic power system.

Momentarily positioning the ANT switch to OFF directs 28 volts d.c. from the right transformer-rectifier bus to pin B of the rotodome rotation selector valve to energize the dome stop solenoid. The rotodome rotation selector valve stops directing 3,000-psi hydraulic pressure to the rotodome rotation constant-speed motor and opens the pressure line of the

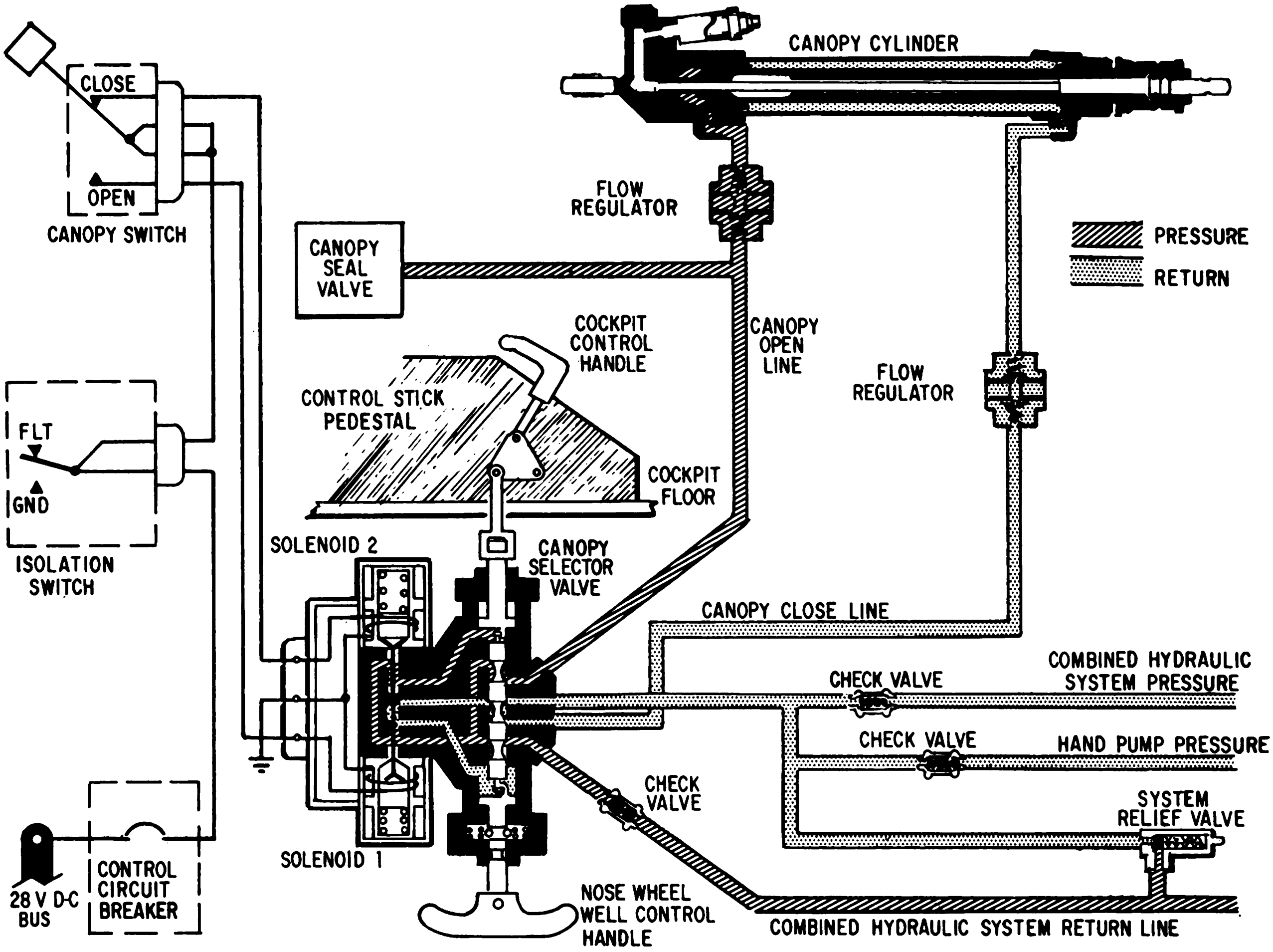


Figure 17-6.—Canopy system schematic.

motor return line through the motor return manifold.

NOSEWHEEL STEERING SYSTEM

The nosewheel steering system (fig. 17-9) such as used on the A-5A aircraft is an electrically controlled, hydraulically operated system that provides a nonlinear relationship between the directional control pedals and the angular position of the nosewheel. The system provides the pilot with adequate directional control of the aircraft during ground operation. The system consists of a hydraulic steer-damper unit, a solenoid-operated shutoff valve, a command potentiometer, a steering amplifier, a steering feedback potentiometer, and an electrical control system. The system is controlled by a ground safety switch on the left-hand main landing gear, the landing gear handle switch, a pushbutton switch on the pilot's stick grip, and the directional control pedals.

Description

The nosewheel steering system is alined for steering operation when electrical circuitry to the steering system is energized. At such time, the solenoid operated hydraulic shutoff valve is opened to supply fluid to the actuator. Simultaneously, all related circuitry for controlling the steering actuator motor is activated. The electrical section of the steering system is essentially a bridge circuit. One side of the bridge

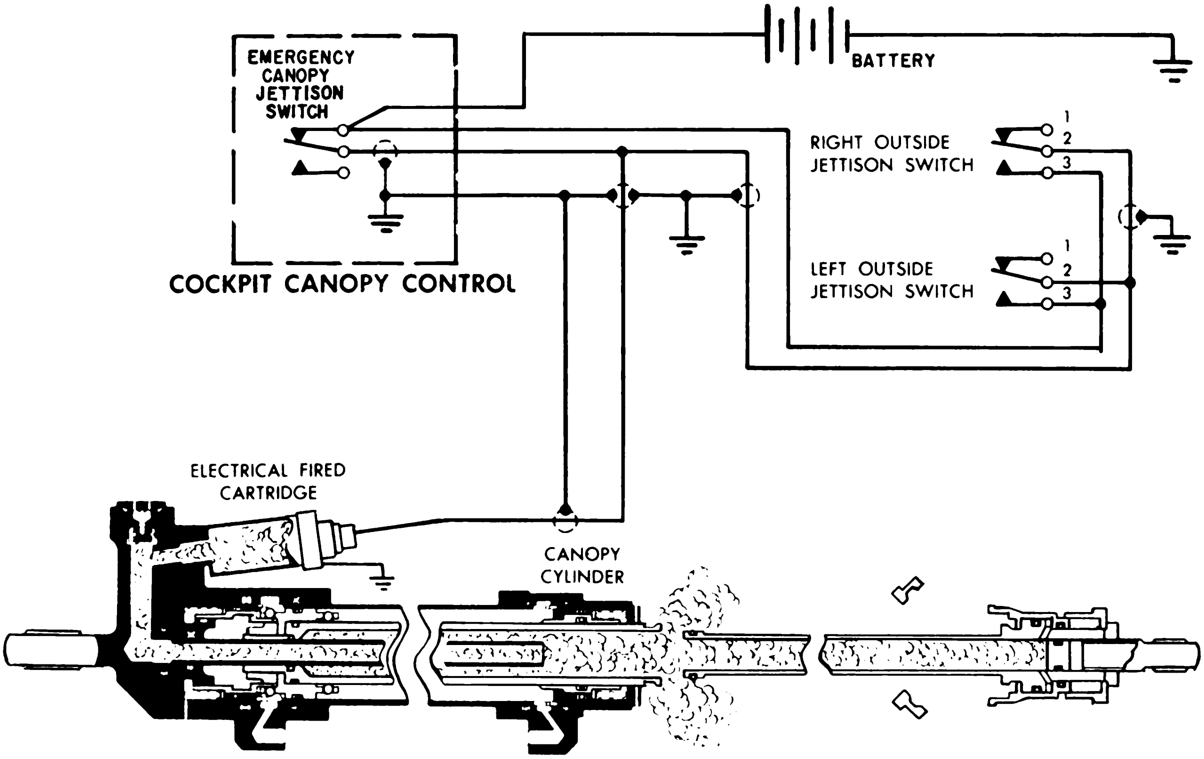


Figure 17-7.—Canopy jettison schematic.

circuit is completed through the command potentiometer: the opposite side through the feedback potentiometer. Output of each potentiometer is supplied to the steering system amplifier. Amplifier output currents are mixed in the torque motor coil of the hydromechanical servo valve and the net signal actuates the servo valve that, in turn, causes nosewheel steering action.

During operation, the nosewheel steering system attempts to maintain symmetry of the electrical bridge circuit. The circuit is symmetrical when equal voltages are supplied to the amplifier from both potentiometers and the servo valve is at a null position. The bridge circuit becomes unbalanced whenever a turn request is initiated by repositioning the command potentiometer wiper. When the resulting bridge circuit is unbalanced, it is reflected as a current differential in the windings of the servo valve torque motor. Therefore, movement of the spool causes hydraulic pressure to be ported to the appropriate side of the actuator piston to cause the nosewheel to turn.

Steer-Damper Unit

The steer-damper unit is an electrically controlled, hydraulically operated package mounted on the nose gear strut assembly. The unit provides both the steering of the nosewheel and the shimmy damping effect required. The package consists of the following: a check valve, a servo valve, a bypass valve, two unidirectional restrictors, the steering actuator, and a fluid compensator.

The check valve prevents reverse flow from the unit to the shutoff valve. The servo valve controls the actuator position by controlling fluid flow to and from the actuator in response to signal variations from the amplifier. The bypass valve closes off the interconnecting passages between both ends of the actuator whenever hydraulic pressure is available to the unit. This permits the actuator to act as a steering unit instead of a damping unit. The unidirectional restrictors provide a restricted reverse flow to dampen nosewheel shimmy. The steering actuator is a balanced piston type hydraulic actuator

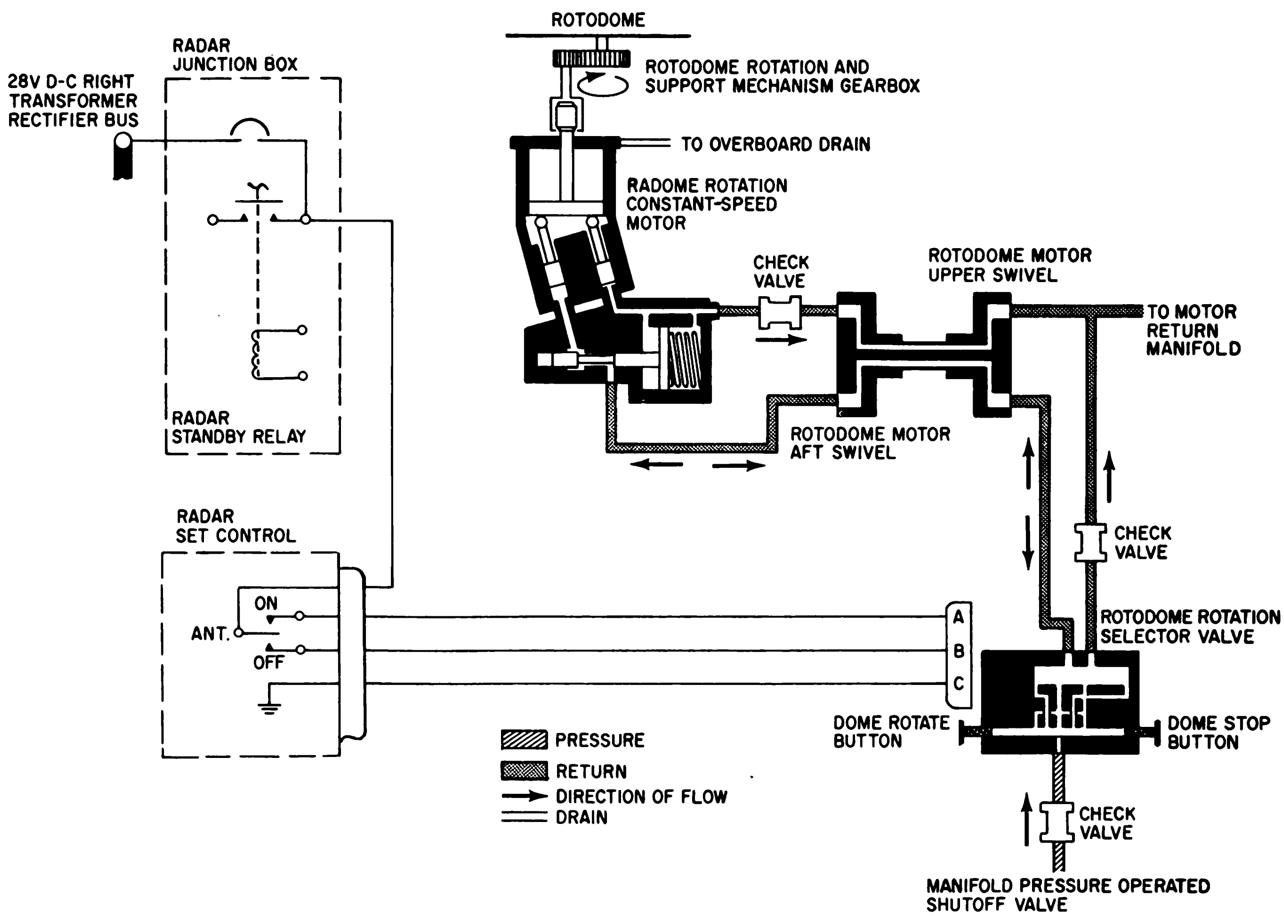


Figure 17-8.—Rotodome rotation schematic.

which provides the force to turn the nosewheel and, in conjunction with the restrictors, provides the shimmy damper action. The fluid compensator is located in the return passage in the unit and traps a quantity of fluid at 40 to 100 psi. The compensator supplies fluid to the actuator through the bypass valve and the restrictor when the unit is being used as a shimmy damper and extra fluid is required to prevent cavitation of the actuator. Since the compensator traps fluid in the actuator, it incorporates thermal relief provisions to prevent excessive pressure buildup within the steer-damper unit.

Steering Shutoff Valve

The steering shutoff valve is a three-way, two-position, normally closed, solenoid-operated valve. The valve controls hydraulic system pressure to the steer-damper unit. When the valve is deenergized, fluid flow is cut off from the steer-damper unit. When the valve is energized (during normal steering or arrested landings), pressure is directed to the check valve, bypass valve, and servo valve in the steer-damper unit.

Steering Command Potentiometer

The steering system uses a rotary type pedal position (command) potentiometer. This potentiometer is mechanically linked to, and driven by, the directional control pedals. It is constructed to provide a nonlinear steering response. The potentiometer sends a signal to the nose gear steer amplifier to indicate the degree and

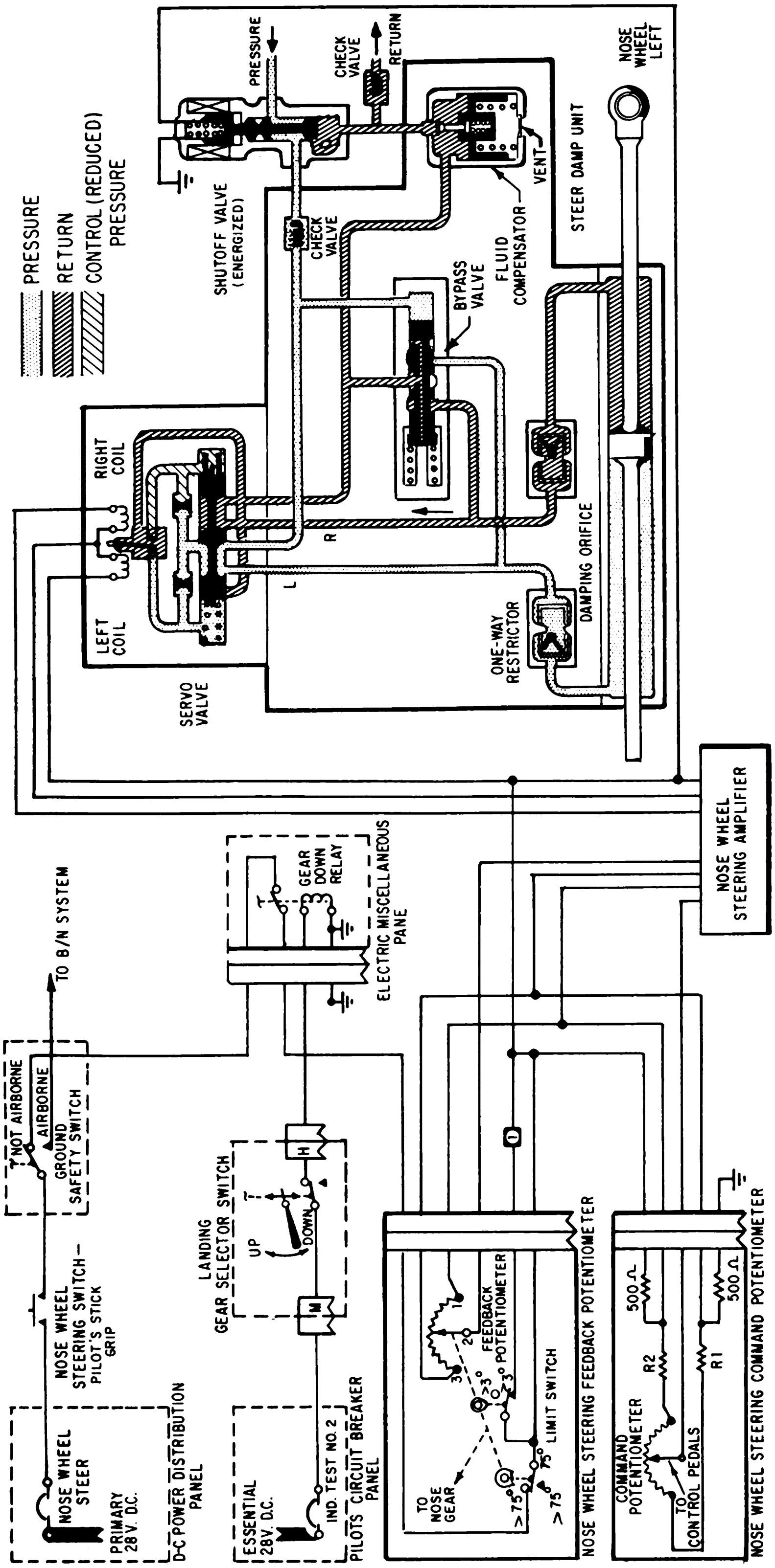


Figure 17-9.—Nosewheel steering system.

direction of turn commanded by the pilot. Moving the potentiometer, with the steering system operating, unbalances a bridge circuit causing the steering amplifier to send a signal to the servo valve to turn the nosewheel.

Steering Feedback Potentiometer

The steering feedback potentiometer assembly consists of a potentiometer that is attached to and driven by the drive arm on the nose gear spindle. As the nose gear moves in response to the pilot's command, the feedback potentiometer feeds back a signal to the steering amplifier. When the signal from the feedback potentiometer matches the signal from the command potentiometer, the amplifier output causes the servo valve to neutralize and stop movement of the nosewheel. The feedback potentiometer assembly contains a swivel disconnect switch which opens when the nosewheel turns 75 to 80 degrees either side of straight ahead. The assembly also contains an arrested landing turn limit switch which opens, if the nosewheel is forced out of the 3-degree range (either side of center), rendering the nosewheel in a damping configuration until the arresting hook is retracted.

Steering System Amplifier

The steering amplifier is a small transistorized differential amplifier. The amplifier is used to detect the differential positions of the command potentiometer and the steering feedback potentiometer. Any difference in signals received will result in a signal being sent to the servo valve to port hydraulic pressure to the steering actuator. This will cause the nosewheel to turn and the steering feedback potentiometer to move. When the feedback potentiometer signal matches the command potentiometer signal, the amplifier causes the servo valve to be neutralized and the nosewheel to cease turning. In addition, the amplifier contains a circuit that provides a centering signal which holds the nosewheel in the straight-ahead position during an arrested landing.

Operation

When the NOSEWHEEL STEERING SWITCH button is depressed (fig. 17-9), power is supplied to the electrical control system and the solenoid-operated shutoff valve. As the valve opens, hydraulic pressure is directed to the servo valve on the steer-damper unit. Signals are sent to the amplifier from the command potentiometer and from the feedback potentiometer on the steering linkage. If these signals are equal, the amplifier signals the servo valve to stay in the neutral position. If the nosewheel (and consequently the feedback potentiometer) does not correspond to the position of the directional control pedals (and command potentiometer), the signals sent to the amplifier will be different and this causes the amplifier to send a signal to the servo valve.

The signal sent to the servo valve will cause the valve to be moved to port pressure to the steering actuator in the steer-damper unit. The hydraulic pressure will cause the actuator to move the nosewheel (and the feedback potentiometer) to a position corresponding to the directional control pedal position (and command potentiometer). When the nosewheel reaches a position corresponding to the pedal's position, the signals to the amplifier will be equal and the amplifier will signal the servo valve to a neutral position. When the servo valve goes to the neutral position (with the steering system energized and hydraulic pressure available) both the pressure and return passages to the steering actuator are blocked off and the actuator is hydraulically locked in position. The steering actuator will remain locked in position until the servo valve is signaled to turn the wheel or hydraulic and/or electrical power is removed from the system. To prevent damage to the aircraft, or reverse steering the system is electrically deenergized whenever the nosewheel is turned more than 75 degrees from the straight-ahead center position. Whenever the steering system is not being used, the steer-damper unit performs the functions of a shimmy damper. Shimmy damping is performed by trapping hydraulic fluid on both sides of the steering actuator piston and forcing this fluid from one side of the actuator to the other side through the restrictor.

MAINTENANCE OF HYDRAULIC SYSTEMS

Although the maintenance of the hydraulic systems of an aircraft is the responsibility of the AMH, the AE must have an understanding of the units which are controlled electrically and be able to determine if the failure is hydraulic, electrical, or mechanical.

The value of teamwork between the AMH and AE to correct the trouble cannot be overemphasized.

Possible causes of trouble in a hydraulic system are usually traceable to one or more of the following sources: fluid supply, air in system, external leakage, internal leakage, restrictions, mechanical linkage, malfunctions, and/or electrical failures.

In tracking troubles in a hydraulic system, it is best to first study the schematic diagrams of the system. Units which cannot possibly be involved can then be eliminated, and time can be saved.

FLUID SUPPLY

The quantity of fluid in the system obviously affects pressure. The reservoir must always contain sufficient fluid to fill the system without permitting the pumps to run dry or air to enter. The fluid level must reach the normal marks on the reservoir sight gage.

AIR IN SYSTEM

Presence of air in the lines and units is detected by an erratic, jerky action when the various mechanisms are actuated. A spongy action of the hand pump is also an indication of air in the system.

Air comes in the system when connections are loose, or when there have been lines disconnected for the removal and reinstallation of units. Air is often drawn into the system when the reservoir fluid level is low.

Bleeding the hydraulic system removes air that becomes trapped in the lines and operating units. Bleeding can be accomplished by operating the affected system several times.

EXTERNAL LEAKS

External leaks in the hydraulic system (where fluid is escaping from the cylinders, valves, or fittings) may generally be found by a visual check. A leak in the system usually causes an accumulation of hydraulic fluid. It may happen that the actual leak is not located directly above the accumulation of fluid, since hydraulic fluid tends to follow structures and tubing to a sharp edge or bend before dropping off. The most efficient method of locating an external leak is to wipe and clean the system and then cycle it. Leaks occur most frequently around fittings, valve connections, and in flexible hose. Leaks around fittings can usually be stopped by tightening loose connections. However, care should be taken to tighten connections only to the proper torque.

INTERNAL LEAKS

Internal leaks are caused by fluid under pressure slipping past an unseated valve or worn packing ring into the return line of the reservoir. The indications of internal leakage are sluggish operation or a dropoff in system pressure.

One method of locating an internal leak is to block off a subsystem by removing and capping the pressure line to the system; then cycle the system. If the pressure does not drop off, the internal leak is in the blocked off subsystem.

RESTRICTIONS

A restriction may be either total or partial. A total restriction is a complete stoppage of fluid flow. A total restriction is indicated when a mechanism will not operate although system pressure is available. A partial restriction is a partial stoppage of fluid flow and will usually cause slow or sluggish operation.

Causes of restrictions may be bent tubing or twisted flexible hose.

Bent tubing should be replaced. A twisted hose should be straightened or replaced if it is damaged.

MECHANICAL LINKAGE MALFUNCTIONS

Mechanical linkage malfunctions are generally indicated by slow or jerky operation of the mechanism or by failure to operate at all. Causes of such malfunctions include broken or bent mechanical parts or linkage, improperly adjusted linkage, and lack of lubrication.

Broken or bent parts should be replaced. Improperly adjusted linkage should be adjusted according to the manufacturer's recommendations in the Maintenance Instructions Manual. All moving parts must be lubricated periodically as specified in the Maintenance Instructions Manual.

ELECTRICAL FAILURES

Since practically all hydraulic systems have some electrically controlled components, the AE

will be generally concerned with virtually all hydraulic systems of the aircraft. Causes of electrical failure could be dirty contacts, improperly adjusted microswitches, loss of voltage, opens in circuits, or faulty solenoid valves.

Refer to chapter 14 of this course for proper troubleshooting techniques of circuits. If hydraulic pressure and voltage are normal, the AMH may disassemble the selector valve, clean, inspect, and test. Never disassemble a solenoid.

PNEUMATIC POWER SYSTEM

The pneumatic power system supplies compressed air for various normal and emergency pneumatic actuating systems. The compressed air is stored in storage cylinders in the actuating systems until required by actuation of the system. These cylinders and the power system manifold are initially charged with compressed air or nitrogen from an external source via a single air charge valve. In flight, the air compressor replaces the air pressure and volume lost through leakage, thermal contraction, and actuating system operation.

The air compressor is supplied with supercharged air from the engine bleed air system. This insures an adequate supply of air to the compressor at all altitudes.

The air compressor may be driven by an electric motor or a hydraulic motor. The system described in this chapter is hydraulically driven. (See fig. 17-10.)

SYSTEM OPERATION

The aircraft utility hydraulic system provides power to operate the hydraulic motor driven air compressor. The air compressor hydraulic actuating system consists of a solenoid-operated selector valve, flow regulator, hydraulic motor, and motor bypass line check valve. When energized, the selector valve allows the system to be pressurized and run the hydraulic motor; when deenergized the valve blocks off utility system pressure, stopping the motor. The flow regulator, compensating for the varying hydraulic system flow and pressures, meters the flow of fluid to the hydraulic motor to prevent excessive speed variation and/or overspeeding of the compressor. A check valve in the motor bypass line prevents system return line pressure from entering the motor and stalling it.

The air compressor is the pneumatic system's pressurizing air source. The compressor is activated or deactivated by the manifold pressure sensing switch which is an integral part of the moisture separator assembly.

The moisture separator assembly is the pneumatic system's pressure sensor-regulator and relief valve. The manifold pressure switch governs the operation of the air compressor. When the manifold pressure drops below 2,750 psi the pressure sensing switch closes, energizing the separator's moisture dump valve and the hydraulic selector valve which activates the air compressor. When the manifold pressure builds up to 3,150 psi the pressure sensing switch opens, deenergizing the hydraulic selector valve to deactivate the air compressor and dump valve, thus venting overboard any moisture accumulated in the separator. The separator is equipped with a thermostat and heating element. The thermostatically controlled wraparound blanket type heating element prevents freezing of moisture within the reservoir, due to low temperature atmospheric conditions.

The safety fitting, installed at the inlet port of the moisture separator protects the separator from internal explosions due to hot carbon particles or flames that may be emitted from the air compressor.

A chemical drier further reduces the moisture content of the air emerging from the moisture separator.

A pressure transmitter senses and electrically transmits a signal to the pilot's cockpit pneumatic pressure indicator. The indicating system is a synchro type that functions exactly like the hydraulic indicating systems.

An air charge valve provides the entire pneumatic system with a single external ground servicing point. An air pressure gage, located near the air charge valve, is used in servicing the pneumatic system. This gage indicates the manifold pressure.

An air filter in the ground air charge line prevents the entry of particle impurities into the system from the ground servicing power source.

MAINTENANCE

Maintenance of the pneumatic power system consists of servicing, troubleshooting, removal and installation of components, and operational testing.

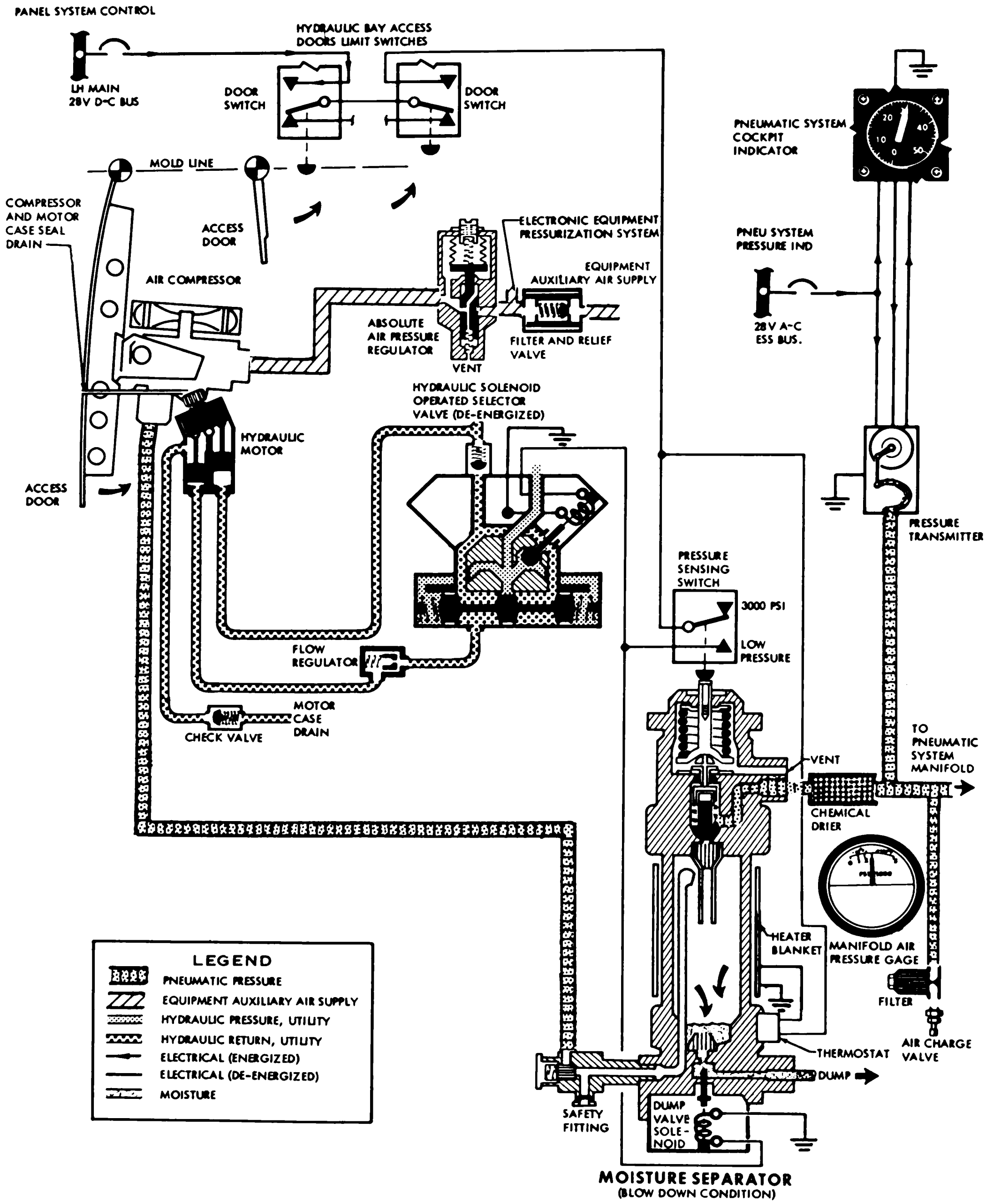


Figure 17-10.—Pneumatic system schematic.

SERVICING

The air compressor lubricating oil level should be checked daily in accordance with the applicable Periodic Maintenance Requirements Manual. The maintenance of the pneumatic systems of aircraft is the responsibility of the AMH; however the AE should have an understanding of the servicing procedures.

TROUBLESHOOTING

Troubleshooting, or fault isolation, is a systematic method of determining the cause of a

system malfunction. This is accomplished by studying the system diagrams (flow diagrams and electrical diagrams) and the troubleshooting charts furnished by the aircraft manufacturer in the applicable Maintenance Instructions Manual.

The troubleshooting charts supply the cause, isolation procedure, and the remedy for some of the more common malfunctions. These charts are organized in a definite sequence under each possible trouble, according to the probability of failure and ease of investigation. In order to obtain maximum value from these charts, they should be used systematically in accordance with the aircraft manufacturer's recommendations.

REMOVAL AND INSTALLATION

When a component of an aircraft pneumatic system has been installed, replaced, disconnected, lines removed, or partially disassembled, the pneumatic system and all equipment affected should be given a complete and thorough operational test. This test should require complete system cycling, until a sufficient check has been made, to determine that its operation and adjustment are satisfactory.

CHAPTER 18

AIRCRAFT COMPASSES

From the beginning of recorded history, man has been vitally interested in navigational aids. Countless devices and methods have been invented and devised. In the present era, with its supersonic speeds, accurate determination of direction has become increasingly important. An error of only a few degrees in a space of minutes will carry the modern aviator many miles off his course.

DIRECT-READING COMPASSES

During the early days of aviation, direction of flight was determined within the aircraft chiefly by direct-reading magnetic compasses. Today the direct-reading magnetic compass still finds use as a standby compass. Direct-reading magnetic compasses used in Navy aircraft are mounted on the instrument panel for use by the pilot, and can be read like the dial of a gage. (See fig. 18-1.)

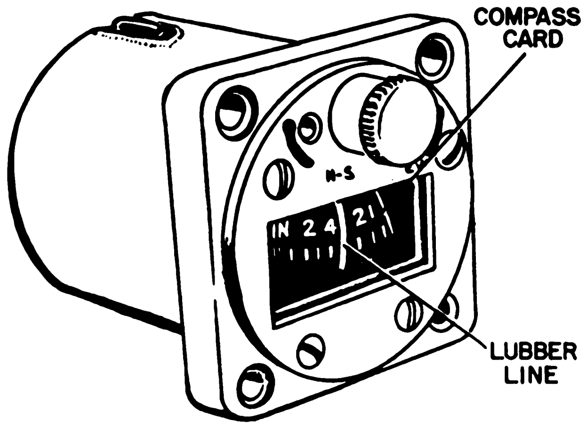


Figure 18-1.—Direct-reading compass.

CONSTRUCTION

A nonmagnetic metal bowl, filled with liquid, contains a compass indicating "card" which provides the means of reading compass indications. The card is mounted on a float assembly and is actually a disk with numbers painted on its edge. A set of small magnetized bars or needles is fastened to this card. The card-magnet assembly is suspended on a jeweled pivot which allows the magnets to aline themselves freely with the north-south direction of the earth's magnetic field. The compass card and a fixed position reference marker called the lubber's line (fig. 18-1) are visible through a glass window on the side of the bowl.

An expansion chamber is built into the compass to provide for expansion and contraction of the liquid, caused by altitude and temperature changes. The purpose of the liquid is to dampen—or slow down—the oscillation of the card. This oscillation is caused by vibration and changes in the aircraft heading. If suspended in air, the card would keep swinging back and forth and be difficult to read. The liquid also buoys up the float assembly, thereby reducing the weight and friction on the pivot bearing.

Instrument-panel compasses for naval aircraft are available with cards marked in steps of either 2° or 5°. Such a compass indicates continuously, and the approximate heading of the aircraft may be read by looking at the card in reference to the lubber's line through the bowl window.

INSTALLATION

Special locations for installing compasses are provided by the Bureau of Naval Weapons specifications. Do not install compasses elsewhere unless specifically authorized by an Aircraft Change. The direct-reading compass must be mounted so that a line passing through the card pivot and lubber's line is parallel to

the longitudinal (fore-and-aft) axis of the aircraft. The card-pivot supporting post must be perpendicular to the horizon when the aircraft is in the level flying position.

Screws and brackets used for mounting compasses must be made of nonmagnetic material. Brackets are usually made of aluminum or brass.

The AE must be especially careful when installing a magnetic compass to make sure that it is placed where magnetic fields will least affect it. The magnetic fields can be set up by nearby electrical equipment, electronic equipment, electrically operated armament, metal structural members of magnetic material, and electrical wiring. A compass can be compensated to take care of any reasonable amount of permanent magnetism near it, but no method of compensation will eliminate the effects of variable magnetic fields. The maximum error of a compass after it is compensated must not be more than 5°.

MAINTENANCE

A compass should be removed and replaced with a serviceable instrument when any of the following conditions exist:

1. Card markings are illegible because of fading, discoloration, or loss of luminous paint.
2. The card does not rotate freely when the aircraft is in the normal flying position. This can be checked by deflecting the card with a small permanent magnet.
3. The bowl is cracked, or the mounting frame or lugs are broken.
4. The compass movement is erratic or does not respond after proper efforts to compensate it (unless erratic behavior is caused by compass location only).
5. The lubber's line is loose or misalined.
6. The compass needs more liquid, or requires major repair.

Compensation

Aircraft magnetic compasses are equipped with devices called compensators, which provide a means of compensating for deviation errors. As pointed out before, the AE cannot eliminate all such errors, but he can reduce them to a minimum by the process called swinging.

Swinging the compass consists of compensating the N-S and E-W headings, then setting the aircraft on every 15 or 30 degrees on the compass rose and noting the difference between the aircraft heading and the indicated heading. The compensators are then adjusted to reduce this difference or deviation to a minimum.

Compensators are of two types. One is known as the universal screw type, and consists of an assembly having a group of small compensating magnets permanently installed in it. Adjustments to change the compensating effect of the assembly are made by means of two adjusting screws, one for north-south compensation, the other for east-west. The other type of compensator employs small, loose magnets which are placed in special chambers on the compass as needed. One such chamber is placed so that its magnets make east-west corrections; the other (at right angles to the east-west chamber) corrects north-south deviation. Compensation is done on the cardinal headings only on present standby compasses in naval aircraft.

Before starting the swinging operation, make certain that all magnetic equipment is secured in the position it will occupy in normal flight. Also be sure that no one near the aircraft compasses during swinging operations has any magnetic materials on his person. Magnetic materials include tools, pocketknives, mechanical pencils, wristwatches, dog tags, bracelets, eyeglasses, officer caps, badges, etc. Remember, too, that a nonmagnetic screwdriver must be used in adjusting universal compensator screws.

The actual swinging of a compass may be accomplished in one of several ways; however, the AE is chiefly interested in ground swings. Ground swinging is usually performed with the aircraft at rest on a compass rose, as shown in figure 18-2.

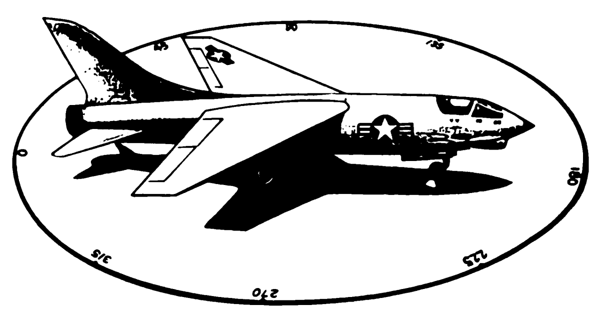


Figure 18-2.—Compass rose, with aircraft on south heading.

Most air stations are equipped with a compass rose, which is much like an oversized card from a navigation compass. The directions shown by it are magnetic directions, and the "north" arrow points toward the earth's north magnetic

pole. A compass rose may also have a line showing true north.

Jacks, lifts, hoists, or any dolly needed to perform the ground swinging job should preferably be made of nonmagnetic material. However, this is not always possible. Devices used in the swinging process must be tested for their effects on the compasses by moving them about the aircraft in a circle with the normal separation distance between the device and the instruments. Devices causing more than one-quarter degree change in the compass reading should not be used.

Trucks, automobiles, railroad cars, and other aircraft contain magnetic metals and should not be within the swinging area where they will have magnetic effect on the compasses of the aircraft being adjusted. Be sure that the compass is in good condition. Examine the compass for clear liquid and proper level. Check to see that the card assembly is level and turns freely when the aircraft's tail is in a level flying position.

Set the compensator so that it has no effect on the main compass magnets. With a loose-magnet compensator this is accomplished by removing all loose magnets from their chambers. Universal screw type compensators are set for zero effect by turning both adjusting screws until the dots on the screws are matched with the dots on the compensator case.

The aircraft is then placed directly on a south magnetic heading over the compass rose, with the tail in a level flying position. (The aircraft engine(s) should be turning and as many pieces of avionics equipment as possible turned on. This will create as many stray magnetic fields as possible and simulate the condition of the aircraft in flight. It may be necessary to take readings with the equipment on an off and record all of the readings.) Note the compass reading and make record of it. From this reading, it is simply a matter of algebraic subtraction (or subtraction of numbers having plus and minus signs) to determine the deviation on the south heading. The deviation is the algebraic difference between the magnetic heading and the compass reading. Deviation is the error in a magnetic compass caused by electromagnetic disturbances in the aircraft.

Following this, the aircraft is placed on a west heading. Again note the compass reading and determine the deviation or difference between the magnetic heading and what the compass reads. The next heading to which the aircraft should be turned is magnetic north. After taking the compass reading on this heading and determining the deviation, subtract algebraically the south heading deviation from the north heading deviation and divide the remainder by two.

For example, if the compass reads 175 1/2° while on the south heading (180°), record this as a deviation of +4 1/2° (180° - 175 1/2°). If the compass reading is too low, the deviation is plus; if the reading is too high, the deviation is minus.

Suppose that on the north (000°) heading the compass reads 006 1/2°. Such a reading is 6 1/2° too high and would be recorded as a deviation of -6 1/2° (000° - 006 1/2°).

The next job is to determine the coefficient of north-south deviation by subtracting, algebraically, the deviation on the south heading from the deviation on the north heading and dividing the remainder by two.

$$\frac{(-6\ 1/2^\circ) - (4\ 1/2^\circ)}{2} = \frac{-11^\circ}{2} = -5\ 1/2^\circ$$

The aircraft is still on the north heading and the compass reads 006 1/2°. Since the coefficient of the north-south deviation is -5 1/2°, the north-south compensator must be adjusted by this amount, and the compass reading on the north heading will now be 001°. This adjustment also corrects the south deviation by the same amount (but in the opposite sense), so that on a south heading the compass will now read 181°. The coefficient of north-south deviation, which is -5 1/2° in this case, is called coefficient "C."

If the compensator is the loose-magnet type, the adjustment for north-south deviation is made by inserting the necessary number of magnets into the lateral (athwartship) chamber of the compensator. If the compass has a universal compensator, make the adjustment by turning the north-south (N-S) compensator screw.

The next step is to determine the east-west deviation. The aircraft must be turned so that its heading is magnetic east, according to the compass rose, and record the compass reading on that heading. Now determine the coefficient of east-west deviation, otherwise known as coefficient "B."

Assume, for example, that the compass reads 276° when the aircraft was on the west (270°) heading, and reads exactly 90° on the east (90°) heading. Coefficient "B" is found by algebraically subtracting the deviation on west

(-6°) from the deviation on east (0°) and dividing by two.

$$\frac{(0^\circ) - (-6^\circ)}{2} = \frac{+6^\circ}{2} = +3^\circ$$

While the aircraft is on the east heading, adjust the east-west (E-W) compensator to add 3° to the compass reading. This reading becomes 93° on the east heading and the compass would read 273° on a west heading. The adjustment is made by turning the E-W screw on a universal compensator, or by adding the necessary magnets in the longitudinal (fore-and-aft) chamber if the compass compensator is of the loose-magnet type. Leaving the aircraft on an east magnetic heading, next compute an overall deviation correction based on what is called coefficient "A." This coefficient is equal to the algebraic sum of the compass deviations on all four cardinal headings (north, east, south, and west), divided by four.

$$\frac{(-6\ 1/2^\circ) + (0^\circ) + (4\ 1/2^\circ) + (-6^\circ)}{4} = \frac{(-8^\circ)}{4} = -2^\circ$$

Instrument panel compasses must be compensated for coefficient "A" if it amounts to 2° or more in either direction. When making this correction, leave the magnetic compensators alone. Compensation for coefficient "A" is accomplished by moving the instrument in its mounting.

Compensation of panel mounted compasses for coefficient "A" can be accomplished either by a slight realinement of the whole instrument panel, or by turning the compass a little with relation to the front of the panel and placing washers or spacers under its mounting screws.

After compensation is completed, the aircraft must be swung again on eight equally spaced headings such as, for example, 0°, 45°, 90°, 135°, 180°, 225°, 270°, and 315°, and the compass readings recorded for each heading on a compass correction card. An illustration of a compass correction card is shown in figure 18-3.

The small, right-hand portion of the compass correction card is intended to be detached and mounted in the aircraft. It is thus available for ready reference, telling the pilot or navigator the comparative compass headings and magnetic headings for these eight readings. The larger portion of the card should be turned over to the maintenance department for insertion into the aircraft maintenance log.

Detailed information on compass swinging is given in the Military Standard, MIL-STD-765. Consult this specification for additional information in connection with swinging, compensating, and calibrating compasses.

GYROSCOPES

Early aircraft were flown by visually alining the aircraft with the horizon; when visibility was poor, it was impossible to fly the aircraft safely. The need for flight instruments to correct this condition caused the development of gyroscopic instruments. The gyroscopic properties of a spinning wheel have made precision instrument flying, precise navigation, and pinpoint bombing practical and reliable. Some of the instruments which depend on a spinning wheel for their operation are the turn-and-bank indicator, directional gyro, gyro horizon, automatic pilot, drift meter, gyrostabilized fluxgate compass, and the inertial navigation system.

PRINCIPLES OF OPERATION

A gyroscope is a spinning wheel or rotor, which is universally mounted; that is, mounted so it can assume any position in space. Any spinning object exhibits gyroscopic properties. However, a wheel designed and mounted to utilize these properties is called a gyroscope. The two important design characteristics of an instrument gyro are (1) great weight for small size (high density), and (2) rotation at high speeds with low friction bearings. The mountings of the gyro wheels are called gimbals; they may be circular rings, rectangular frames, or, in flight instruments, a part of the instrument case itself. A simple gyroscope is illustrated in figure 18-4.

The two general types of mountings for gyros are the free or universal mounting and the restricted or semirigid mounting. The type mounting used depends on the property of the gyro to be utilized.

A gyro can have different degrees of freedom, depending on the number of gimbals in which it is supported, and the way in which the gimbals are arranged. The term "degrees of freedom," as used here, must not be confused

	COMPENSATING SWING			RESIDUAL SWING	
	ACTUAL HEAD (M)	AIRCRAFT COMP.	DEV'N	ACTUAL HEAD (M)	AIRCRAFT COMP.
N 000	000	006½	−6½	000	001
				045	045
E 090	090	090	0	090	093
				135	135
S 180	180	175½	+4½	180	181
				225	225
W 270	270	276	−6	270	273
				315	315
	(1)	(2)	(1) − (2)	(3)	(4)

IF SWINGING COMPASS USED AHEAD OF AIRCRAFT ADD OR SUBTRACT 180 DEGREES

COEFF $C = \frac{N-S}{2} = \frac{(-6\frac{1}{2}°)-(4\frac{1}{2}°)}{2} = -\frac{11}{2} = -5\frac{1}{2}°$

COEFF $B = \frac{E-W}{2} = \frac{(0°)-(-6°)}{2} = \frac{+6°}{2} = +3°$

COEFF $A = \frac{N+E+S+W}{4} = \frac{(-6\frac{1}{2}°)+(0°)+(4\frac{1}{2}°)+(-6°)}{4} = \frac{(-8°)}{4} = -2$

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AIRCRAFT COMPASS

BY

TO FLY	STEER	TO FLY	STEER
N	001	180	181
15	016	195	196
30	030½	210	210
45	045	225	225
60	061	240	240½
75	078	255	256½
90	093	270	273
105	102	285	286½
120	121	300	300½
135	135	315	315
150	150	330	330
165	165½	345	346

Figure 18-3.—Compass correction card.

with an angular value as degrees of a circle. The term as used with gyros is an indication of the number of directions in which the rotor is free to move. (Some authorities consider the spin of the rotor as one degree of freedom, but most do not.)

A gyro enclosed in one gimbal, such as the one shown in figure 18-4. has onlv one degree of freedom. This is a freedom of movement back and forth at a right angle to the axis of spin. When this gyro is mounted in an aircraft, with its spin axis parallel to the direction of travel and capable of swinging from left to right, it has one degree of freedom. The gyro has no other freedom of movement. Therefore, if the aircraft should nose up or down, the geometric plane containing the gyro spin axis would move exactly as the aircraft does in these directions. However, if the aircraft should turn right or left, the gyro would not change its attitude, since it has a degree of freedom in these directions.

A gyro mounted in two gimbals normally has two degrees of freedom. Such a gyro can assume and maintain any attitude in space. For illustrative purposes, consider a rubber ball in a bucket of water. Even though the ball is supported by the water, it is not restricted as to attitude by the water, and can lie with its spin axis pointed in any direction. Such is the case with a two-degree-of-freedom gyro (often called a free gyro).

This means that if the base surface turns around the outer gimbal axis, or around the inner gimbal axis, the gyro spin axis remains fixed. In other words, the gimbaling system isolates the rotor from the base rotation. The universally mounted gyro is an example of this type. Restricted or semirigidly mounted gyros are those mounted so that one of the planes of freedom is held fixed in relation to the base.

Properties of Gyroscopes

Practical applications of the gyro are based upon two fundamental properties of gyroscopic

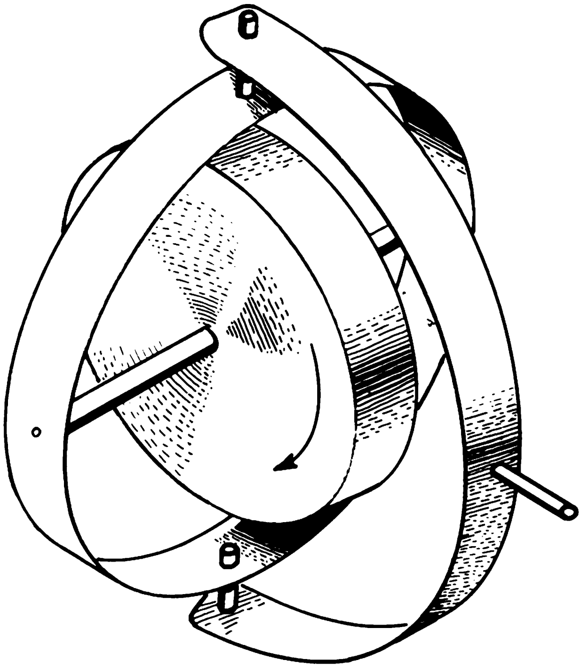


Figure 18-4.—Simple gyroscope.

action: (1) rigidity in space, and (2) precession.

Newton's first law of motion states: "A body at rest will remain at rest, or if in motion will continue in motion in a straight line, unless acted upon by an outside force." An example of this law is the rotor in a universally mounted gyro. When the wheel is spinning, it has the ability to remain in its original plane of rotation regardless of how the base is moved. This is shown in figure 18-5. The gyroscope holds its position relative to space, even though the earth turns around once every 24 hours.

The factors which determine how much rigidity a spinning wheel has are found in Newton's second law of motion which states: "The deflection of a moving body is directly proportional to the deflective force applied and is inversely proportional to its mass and speed." To obtain as much rigidity as possible in the rotor, it is given great weight for size, and rotated at high speeds. To keep the deflective force at a minimum, the rotor shaft is mounted in bearings which are as frictionless as possible. The basic flight instruments which utilize the gyroscopic property of rigidity for their principle of operation are the gyro horizon, the directional gyro, and any gyrostabilized compass system; consequently, their rotors must be freely or universally mounted.

Precession is the resultant action or deflection of a spinning wheel when a deflective force is applied to its rim. When a deflective force is applied to the rim of a rotating wheel, the resultant force is 90° ahead of the direction of rotation and in the direction of the applied force. This is illustrated in figure 18-6. The rate at which the wheel precesses is inversely proportional to the speed of the rotor and directly proportional to the deflective force. The force with which a wheel precesses is the same as the deflective force applied (minus the friction in the gimbal ring, pivots, and bearings). If too great a deflective force is applied for the amount of rigidity in the wheel, the wheel precesses and topples over at the same time.

Any spinning mass exhibits the gyroscopic properties of rigidity in space and precession. The rigidity of a spinning rotor is directly proportional to the weight of the rotor and its speed, and inversely proportional to the deflective force.

GYROSTABILIZED COMPASSES

Compass systems utilizing gyrostabilization are designed to overcome the disadvantages of

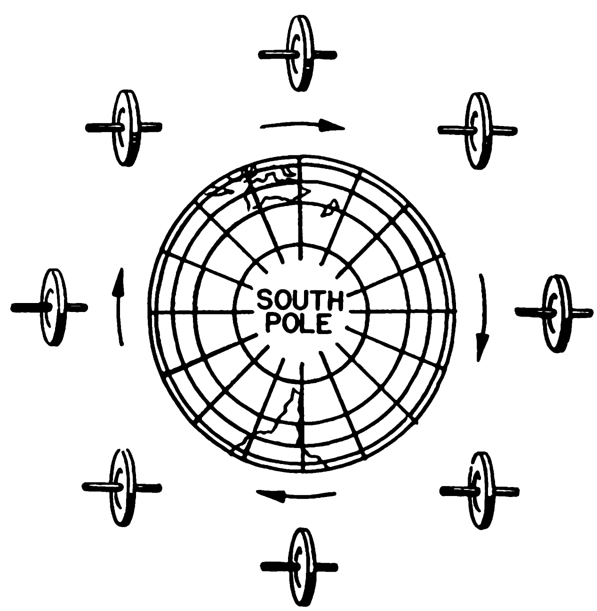


Figure 18-5.—Action of a freely mounted gyroscope.

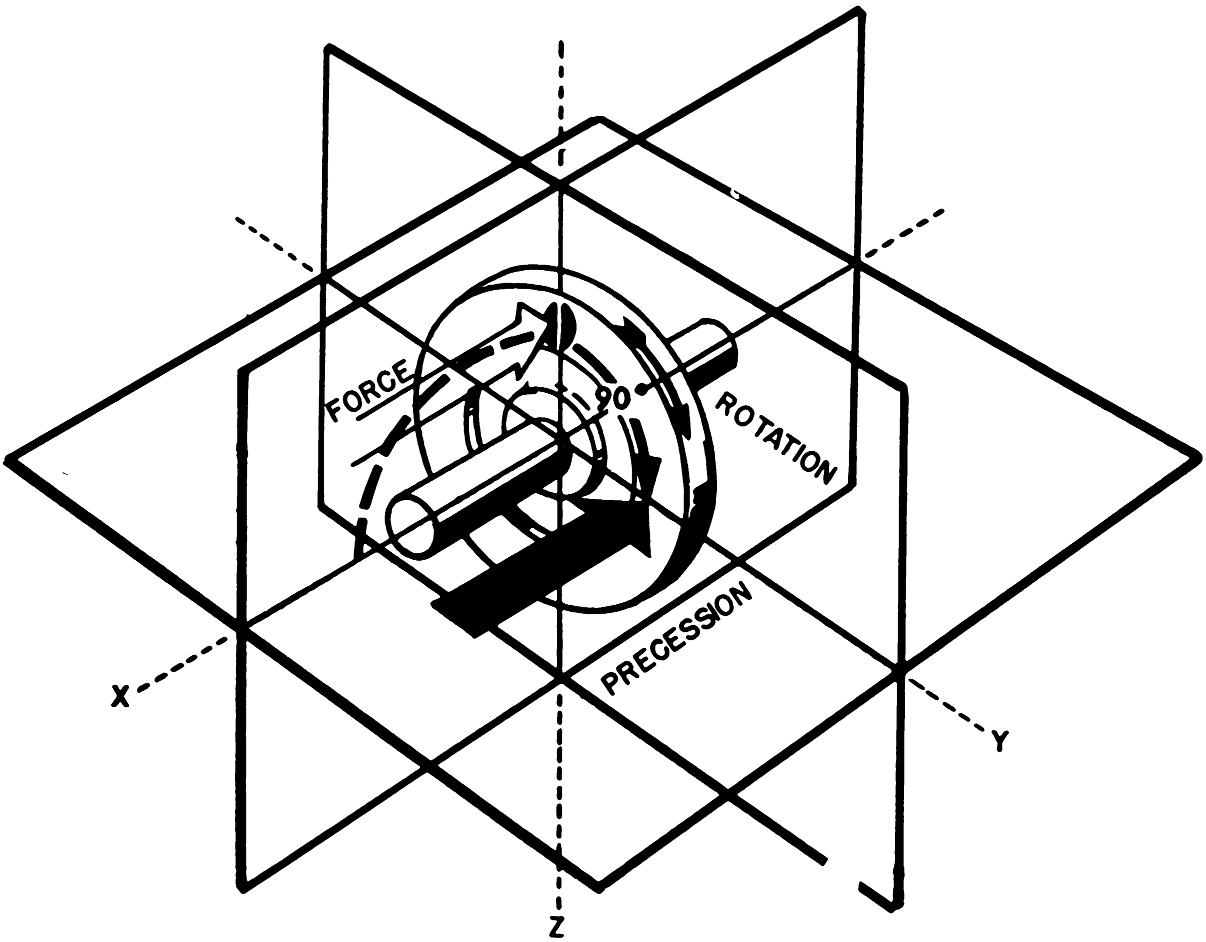


Figure 18-6.—Precession resulting from deflective force.

the direct-reading panel type compass. These systems consist of five basic parts—transmitter, amplifier, power junction box, master direction indicator, and repeater indicator. A system of this type is commonly known as the gyro fluxgate compass.

FLUXGATE COMPASS OPERATION

The transmitter (fig. 18-7) is made up of a vertical-seeking gyro and a 2-winding, 3-phase transmitter. The gyro maintains the transmitter in a horizontal attitude for an accurate reading, regardless of the flight attitude of the aircraft. The winding of the transmitter consists of a primary and secondary wound on a saturable core.

The amplifier unit (fig. 18-8) consists of a 487 1/2-cycle oscillator, 975-cycle oscillator, a signal amplifier, and a power amplifier.

The power junction box (fig. 18-9) is the power distribution point for the various d-c and a-c voltages that are necessary to operate this equipment.

The master direction indicator (fig. 18-10) consists of an Autosyn, a low inertia motor, and a Magnesyn. This unit drives the compass indicator dial.

The repeater indicator (fig. 18-11) is a Magnesyn. As many as six units can be connected to the equipment for the purpose of indicating direction at different positions in the aircraft.

The fluxgate is the triangular-shaped directional reference element located in the transmitter. When its primary windings are excited by the single-phase, 487 1/2-cycle power supply, furnished by an oscillator in the amplifier, the core becomes saturated and demagnetized. This happens once during each

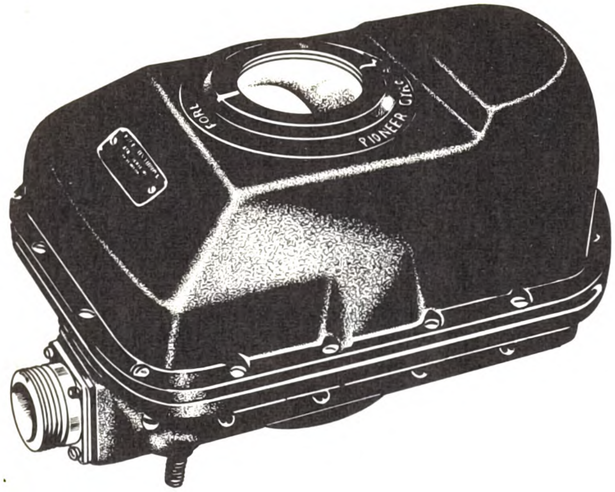


Figure 18-7.—Gyro fluxgate transmitter.

positive alternation and once during each negative alternation of the exciting current, or 975 times per second. However, no inductive effects are produced in the secondary windings by the primary excitation. Its sole function is to saturate the core at regular intervals.

The core becomes temporarily demagnetized at those points in the cycle where the exciting current passes through zero. Flux lines of the horizontal component of the earth's magnetic field then flow through the core because, when demagnetized, it presents a path of lower reluctance than the surrounding air.

Each time the exciting current rises to a positive or negative peak, the flux lines of the earth's field are no longer concentrated in the core because, when magnetized by the exciting current, it no longer presents a path of least resistance.

By being alternately excluded from the core and then allowed to pass through it, the constant flux of the earth's magnetic field is made to have an alternating effect by cutting the secondary windings on the core and inducing into them an electrical impulse or signal.

The fluxgate cores are mounted in the form of a triangle, as illustrated in figure 18-12. The strength of the signal voltage developed across each secondary is dependent on the angle at which the core on which it is wound is positioned with respect to the earth's magnetic field. Only one possible combination of voltages, therefore, exists for any given compass heading.

The fluxgate must be kept in a horizontal position because the directional reference voltages, which it furnishes, vary in correct proportion to each other only when the position of the fluxgate is changed with respect to the horizontal component of the earth's magnetic field. If the fluxgate were allowed to pick up the vertical component of the earth's field, distorted compass readings would result.

The vertical seeking gyro provides the means of holding the fluxgate in a horizontal position with respect to the earth, not only in straight flight but also during such maneuvers as climbs,

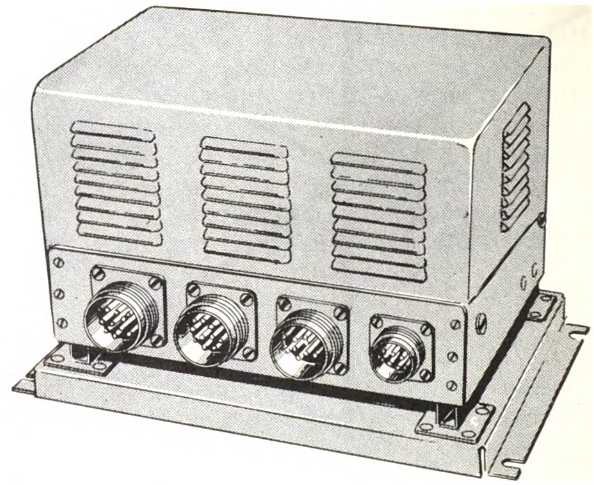


Figure 18-8.—Gyro fluxgate amplifier.

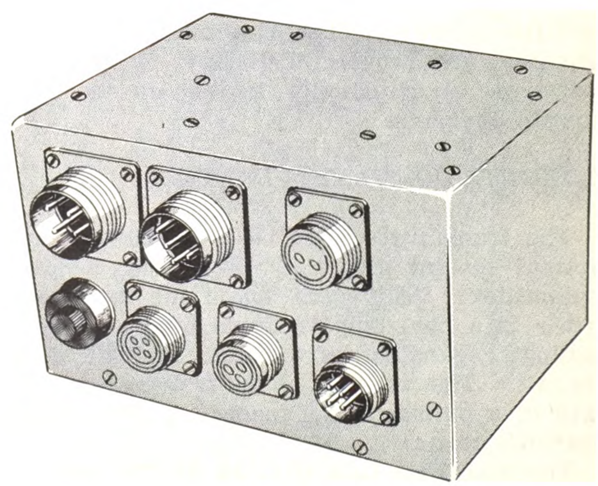


Figure 18-9.—Power junction box.

Figure 18-10.—Master direction indicator.

dives, and turns. Turning error is, for all practical purposes, eliminated.

Three leads are connected to the fluxgate secondary windings, one at each apex of the triangle, to permit the signal voltages induced by the earth's magnetic field to be taken off. The voltage in each one of the leads differs from the voltage in the other two. Turning the fluxgate with reference to the earth's magnetic field immediately changes the voltage in each of the three takeoff leads. Their sum, however, remains constant.

The three leads from the fluxgate secondary windings are connected in parallel to the stator of a followup Autosyn in the master direction indicator. The voltages in these three leads cause currents to flow and set up an alternating directional magnetic field across the followup Autosyn stator. This magnetic field shifts whenever any change occurs in the three stator voltages as a result of a change in the heading of the aircraft.

The rotor of the followup Autosyn, in the master direction indicator, lies normally in a null position; that is, with its poles at right angles to the stator field. It is important to note that as long as the Autosyn rotor is in a null position, no signal is induced in the rotor by the stator field. However, if the stator field shifts, the rotor is no longer in a null position, and an electrical impulse or signal can be obtained from the rotor windings. Shifting the stator field in a clockwise direction off null, with respect to the rotor, produces a signal of opposite phase to that produced when the stator field shifts off null in a counterclockwise direction. (See fig. 18-13.)

Because the followup Autosyn rotor signal is low in voltage, it is fed through a vacuum tube amplifier where it receives two stages of voltage amplification and one of power amplification. The output of the voltage amplifier circuit is fed to the control grid of a power amplifier tube. The output of this tube supplies current at 975 cycles to the variable phase of the low inertia motor in the master direction indicator. Power for the fixed phase of the same motor is supplied by the 975-cycle oscillator circuit in the amplifier.

This 975-cycle oscillator is electron-coupled to the 487 1/2-cycle oscillator which provides excitation for the fluxgate primary windings so that they will be locked together. This locking relationship must be maintained to keep the frequency of the fixed and variable phases of the low inertia motor in step and maintain accurate indications on the indicators. Whereas the fixed phase remains constant, the variable

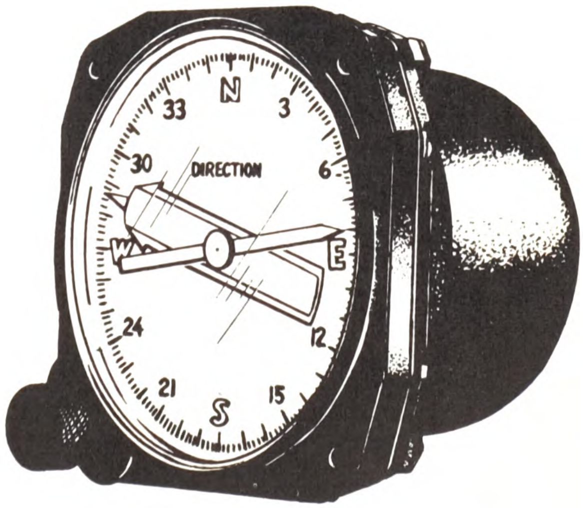


Figure 18-11.—Repeater indicator.

phase can rise or fall in voltage, and undergo phase displacement whereby it will either lead or lag the fixed phase by 90°. The frequency of either phase, however, must not vary.

In the amplifier, the phase relationship between the output of the 6V6GT power tube (variable phase of motor) and the output of the 6V6GT tube used as a 975-cycle oscillator (fixed phase of motor) is directly controlled by the phase of the followup Autosyn rotor signal. This signal is impressed upon the grid of the power tube.

A phase reversal in the followup Autosyn signal will cause the motor to reverse its direction of rotation. A rise or fall in the followup Autosyn signal voltage amplitude will cause the motor to increase or decrease its speed.

The low inertia motor, in the master direction indicator, performs two functions: First, it supplies the necessary torque to drive the corrected and uncorrected dials and the correction mechanism, and second, it drives the followup Autosyn to a new null position.

The rotor of the low inertia motor is mechanically connected, through a gear train, to the rotor of the followup Autosyn so that, while the low inertia motor is driving the dial to a new heading, the rotor of the followup Autosyn is being driven to a null position where its poles are again at right angles to the stator field.

When this new null position is reached, the followup Autosyn signal dies out and the low inertia motor stops running, until a change in the heading of the aircraft again causes a signal to be induced in the followup Autosyn rotor.

In the event that the repeater indicators are used in the system, they will be electrically connected in parallel to the stator of the transmitting Magnesyn in the master direction indicator.

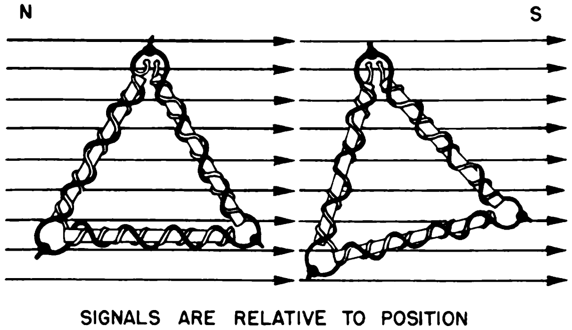


Figure 18-12.—Fluxgate in earth's field.

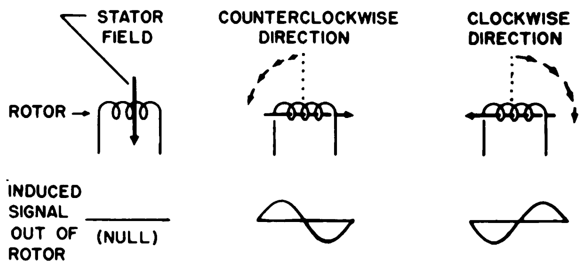


Figure 18-13.—Autosyn stator magnetic field shifting.

The permanent magnet rotor of the transmitting Magnesyn is mechanically coupled to the master direction indicator gear train. Any change in its position causes a shift in the stator field in each repeater indicator. Since the hand on the repeater indicator is directly attached to the shaft of the rotor, which is also a permanent magnet rotor, the position of the hand coincides with the position of the rotor as it follows the shifting stator field.

In addition, the repeater indicator compass reading is always automatically compensated for deviation because the transmitting Magnesyn rotor is driven by that part of the gear train which represents the output side of the correction mechanism. In the event that the pointers vary, a compensating card is necessary.

Figure 18-14 shows an operational schematic diagram of the gyro fluxgate compass system—study if for a better understanding of the system.

The caging system in the gyro fluxgate compass is mechanical in operation but electrically controlled. A caging motor in the gyro fluxgate transmitter actuates two roller arms in pitch by engaging a detent cam on the gyro housing; the other arm cages the gyro in bank by engaging a similar detent cam on the gyro gimbal. The caging motor is controlled by either a toggle type or pushbutton type switch, depending on the installation.

G-2 COMPASS SYSTEM

The components of the G-2 compass system operate together to give the advantages of both the magnetic compass type and the gyro type of direction indicator. The long-period accuracy of the average magnetic compass heading is retained, and also the short time accuracy of the gyro, while the short-period oscillation of

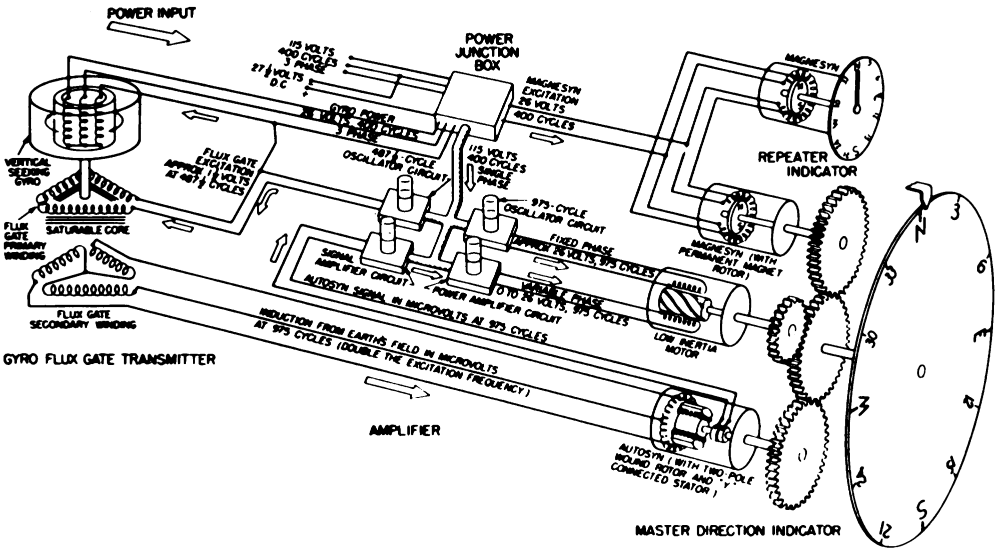


Figure 18-14.—Gyro fluxgate compass system.

the magnetic compass and the longtime drift error of the gyro are eliminated.

The G-2 compass system is designed to provide an accurate and stable indication of the heading of the aircraft in azimuth at all times. It can also provide suitable signals from an automatic pickoff coil so that it may be used as the directional gyro control in auto pilot installations. Each system is composed of the following major components: a master direction indicator, an amplifier, a remote compass transmitter, and a remote compass repeater type indicator. (See fig. 18-15.)

The magnetic heading of the aircraft is detected by means of the remote compass transmitter. (See fig. 18-16.) This transmitter is connected to the detector circuit of the master direction indicator, and any deviation between the compass transmitter and the master direction indicator sets up a signal in the detector circuit. This signal is transmitted to the amplifier where it is modified and sent to the torque motor of the master direction indicator. By means of this signal, the torque motor precesses the gyro element of the master direction indicator until agreement between the master direction indicator and the compass transmitter occurs. The precession rate of the gyro element is approximately 4° per minute. As a result, it does not rapidly follow every movement of the compass transmitter, but gives a stabilized average indication of the course of the aircraft. The short-period oscillations of the compass transmitter do not affect the indication. Because the heading of the gyro element is constantly being changed by the signal from the remote compass transmitter, the drift of the gyro element is eliminated.

Included in the master direction indicator, and located in the center of the dial, is the correspondence indicator which is electrically connected to the remote compass transmitter. This correspondence indicator is always in agreement with the remote compass transmitter and provides an unstabilized indication of the course of the aircraft. (See fig. 18-15 (B).)

Provision is made for removing the effect of the compass transmitter on the heading of the gyro element by means of a control switch in the cockpit. When this switch is in the free directional gyro position, the gyro operates as a free gyro subject to drift, but has the advantage of giving the heading of the aircraft in magnetically unreliable regions, such as the north and south magnetic poles and on the decks of aircraft carriers.

The master direction indicator is provided with a resetting knob located on the front of the instrument in the lower left-hand corner. By means of this knob, the instrument may be set

manually to any desired heading. Upon release of the resetting knob, the gyro element automatically becomes uncaged at its new setting. This resetting device is used when starting the gyro, since the gyro element may have stopped at any heading, and otherwise would require several minutes to correct itself to indicate the true heading of the aircraft.

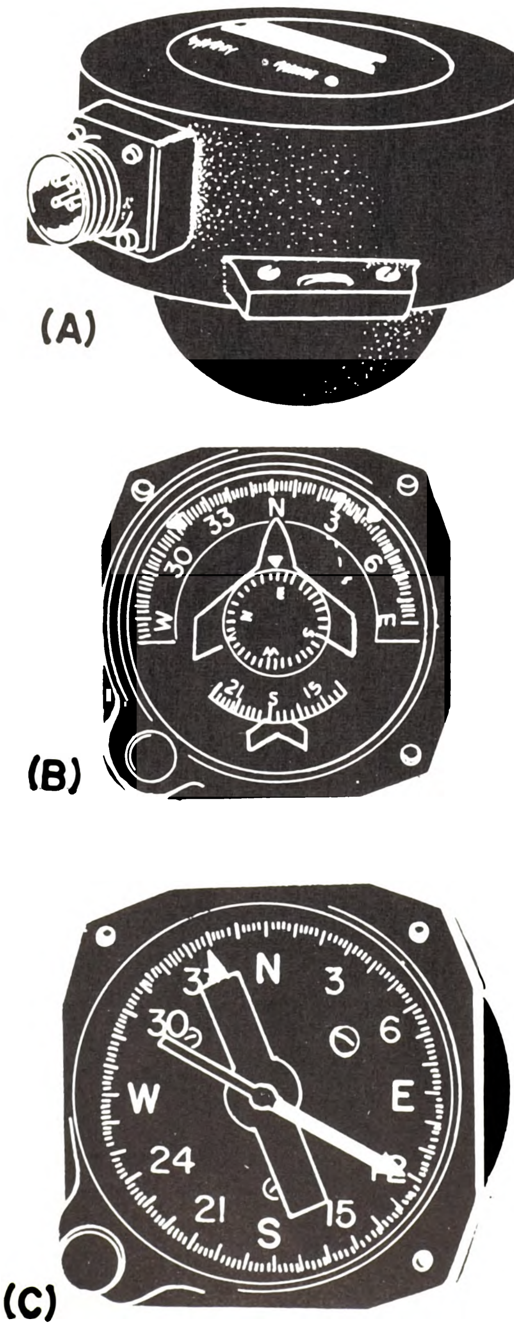


Figure 18-15.—Components of G-2 compass. (A) Remote compass transmitter; (B) master direction indicator; (C) remote compass repeater indicator.

The G-2 compass system indicates any heading of the aircraft through the entire 360° of azimuth. The operation of the system is not affected by maneuvers which the aircraft may be expected to perform, including banks and rolls which are beyond the limits of conventional directional gyros.

The G-2 compass system is designed to operate from a 115-volt, 3-phase, 400-cycle, a-c power supply. A standard 27.5-volt, d-c power supply is also required. Study figure 18-16 for a better understanding of the circuit.

MA-1 COMPASS SYSTEM

One compass system utilized by the Navy is the MA-1. It combines the action of a magnetic compass and a directional gyroscope to give an accurate, reliable, and continuous azimuth heading. For instrument flights the compass is the most essential navigational aid. The MA-1 compass system obtains reliable readings by combining the most desirable features of the gyro and the magnetic compass.

The system consists of a remote compass transmitter, a controller, an amplifier indicator, and a directional gyroscope. The MA-1 compass system is discussed in the Navy Training Course AE 1 & C, NavPers 10349-A.

COMPASS-CONTROLLED DIRECTIONAL GYROS

The gyroscope, when used in a directional indicator, furnishes a highly accurate reading for a short period of time (approximately 15 minutes). Such a gyro instrument can be set to a known magnetic heading as a reference, and will give an accurate, stable reading of magnetic heading until precession becomes too severe. Some modern precision gyros are accurate for very long periods. In compass-controlled directional gyro systems such as the G-2, S-2, and MA-1, the short-term accuracy of a gyro is combined with the long-term accuracy of a magnetic compass. The construction of these systems is such that an electric signal is generated whenever there exists a difference between the gyro heading and the actual magnetic heading of an aircraft.

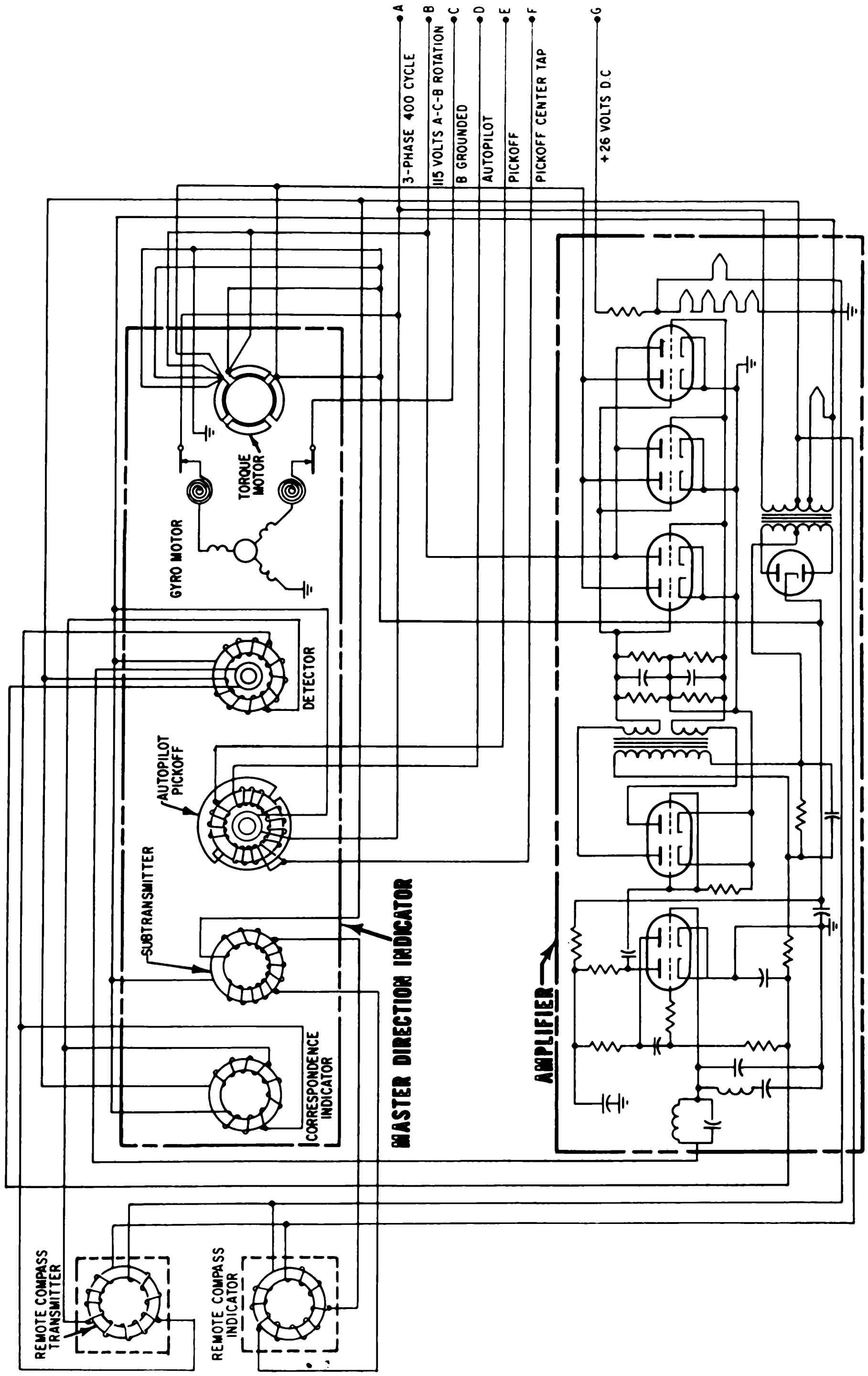


Figure 18-16.—Schematic diagram of G-2 compass system.

In the G-2 system, this is performed within the master direction indicator (G-2 indicator) in the cockpit. This electric signal goes to an electronic amplifier. When receiving this signal, the amplifier transmits power back into the G-2 indicator and causes the gyro to precess in such a direction as to aline itself with the magnetic heading. In this manner, the gyro heading is "slaved" to the magnetic heading. An important feature is the fact that the slaving action takes place rather slowly (approximately 4° per minute). At this rate of precession, the gyro is caused to stay close to the magnetic heading over a long period of time, but is not caused to follow short-term oscillations to any visible degree. The G-2 may also be used as a free directional gyro; that is, an electric switch may be opened to stop the slaving action.

In the S-2 and MA-1 compasses, the gyroscope is not located in a cockpit indicator. The gyroscope is located at some point remote from the cockpit, but direction readings are transmitted to a cockpit indicator through a typical instrument synchro system. The S-2 and MA-1 are also slaved to a magnetic heading.

C-8 COMPASS SYSTEM

Another gyrostabilized compass system which is in use on naval aircraft is the C-8 compass system. This compass is suitable for polar navigation, as well as normal navigation in the lower latitudes, because of its improved directional gyro and provisions for latitude correction.

The C-8 system consists of five basic components, shown in figure 18-17.

The operation of the C-8 compass system may be more easily understood by referring to the block diagram in figure 18-18.

As the directional gyro comes up to speed, it is leveled by the leveling torque motor (torquer). The voltage for the control field of the torque motor is taken from one leg of the gyro motor. The fixed field of the torque motor is fed from a 115-volt line. When the gyro is erected, its axis stabilizes in an alinement that has no directional significance; that is, it will not necessarily be pointing to magnetic north.

Whatever the direction of its axis, the gyro will mechanically position the rotor of the heading synchro transmitter. Directional information is fed from the stator of the gyro-heading synchro transmitter to the stator of a heading synchro control transformer in the servo loop. The rotor of the synchro control transformer will thus develop an error signal whose magnitude and phase will be proportional to the angular error between the direction of the stator's field and the position of the servo loop shaft.

The error signal developed is amplified in the servoamplifier, which causes the servomotor to drive the loop shaft, and hence the synchro control transformer rotor, in such a direction as to null the synchro error signal. The servomotor drives the shaft through a speed reduction gear train. Under these conditions, the servo loop shaft and the data synchro transmitters will take up and maintain a position which will be directly dependent upon the position of the gyro's axis.

Equipment such as a flight computer system, radio magnetic indicator, ground positional indicator, or a radar stabilization repeater may be driven from either of the two data synchro transmitters included in the servo loop of the system. Also, heading information for an automatic pilot may be taken directly from the automatic pilot synchro which is located in the directional gyro unit. The excitation of these three synchros is supplied externally, which eliminates any signal phasing problems.

Headings are set by rotating the SET HEADING control on the compass controller to the right or left. This action does two things. First, it opens the magnetic clutch shown in figure 18-18 so as to isolate the heading synchro control transformer rotor from the servo loop shaft. By doing this, the stator and rotor remain in the same relative position and thus do not develop any error signal. Second, an a-c voltage of a given phase is fed into the servoamplifier, which causes the servomotor to turn the servo loop shaft in the desired direction. This action may be performed at high speed for rapid slewing to the approximate heading and at a slow speed for accurate alinement. As soon as the proper heading is reached, the SET HEADING control is released, the magnetic clutch closes, and significant heading information from the directional gyro is presented to the data synchro transmitters through the servo loop.

When the compass system is operated in the directional gyro (DG) mode, a heading is set in as described above. After this has been accomplished, the output synchro transmitters show all heading changes and is directly dependent upon the stability of the gyro. The

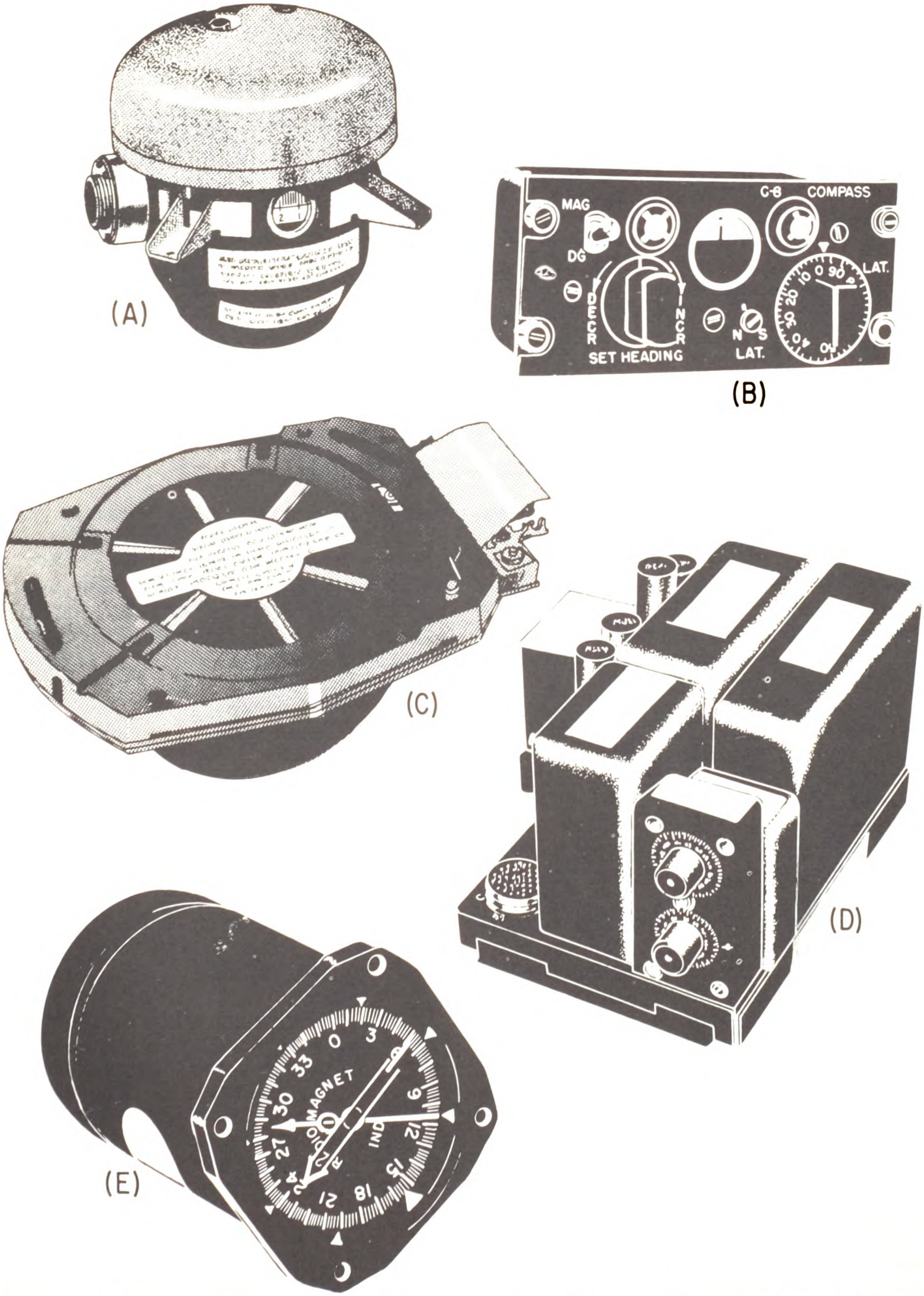


Figure 18-17.—C-8 compass system. (A) Directional gyro; (B) compass controller; (C) transmitter (flux valve); (D) amplifier; (E) remote indicator.

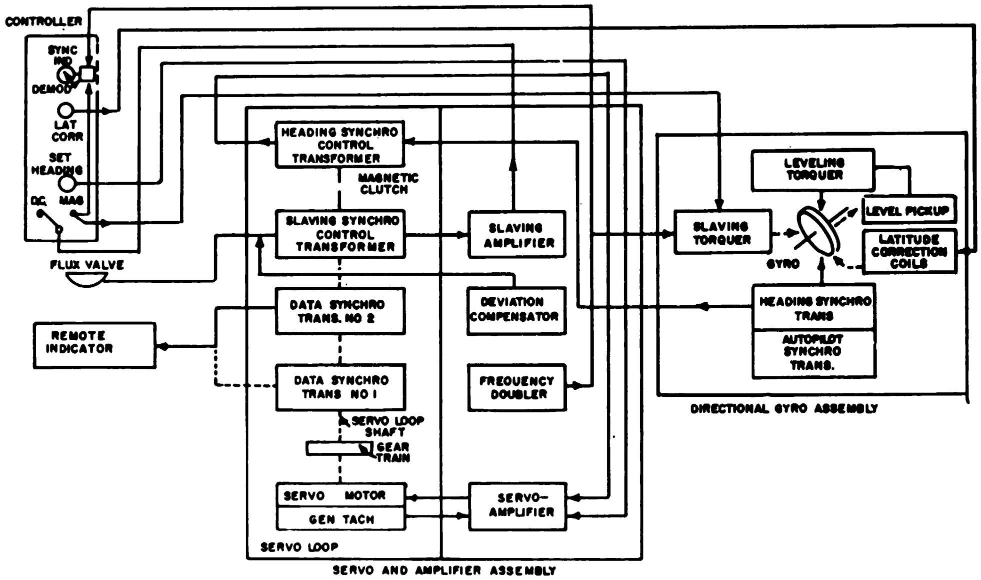


Figure 18-18.—Functional block diagram of C-8 system.

random drift of the unslaved gyro is not more than ±3° per hour.

To compensate for the effects of the earth's rotation, a voltage proportional to latitude is fed to one of the two precession coils. One coil is for compensation in north latitudes, and the other for south latitudes. These coils create magnetic fields which cause the gyro to precess at such a rate as to cancel out the earth's rotational effect.

During the compass-controlled mode of operation, a flux valve supplies heading information to the stator of the slaving synchro control transformer. When angular differences exist between the directional information vector in the slaving synchro control transformer stator and the position of its rotor, error signals are developed which are fed into the slaving amplifier. Here the signals are amplified, and then fed through the MAG DG switch in the controller to the slaving torque motor which, in turn, makes the gyro precess in such a direction as to null the error signal developed in the slaving synchro control transformer. When the null is reached, the servo loop shaft is then in line with the directional information vector from the flux valve and the system is synchronized. The two data synchro transmitters are then able to furnish useful azimuth information.

As with all slaved gyro systems, the gyro's slaving rate is sufficiently slow (1° to 2° per minute) so that it does not respond to rapid fluctuations of the magnetic heading but only to average azimuth changes.

Deviation Compensator

The deviation compensator module of the amplifier assembly consists of three potentiometers, two of which are ganged (fig. 18-17 (D)), by which single-cycle error in the flux valve may be eliminated. To effectively eliminate the magnetic effects, it is necessary to develop within the flux valve a magnetic field which is equal in magnitude and opposite in direction to the disturbing magnetic field created by the aircraft at the location of the flux valve.

The compensation circuit (fig. 18-19) has two controls, one for north-south correction and one for east-west correction. By various settings of these controls, corrective magnetic fields of different magnitudes can be developed in any direction from 0° to 360°. The N-S control potentiometers enable the voltages applied on legs B and C to be made equal, or to be increased on leg B and decreased on leg C simultaneously and vice versa. If the d-c voltages applied to the legs A, B, and C are all exactly equal to the neutral reference voltage as shown in figure 18-19 (A), when the dials are set at

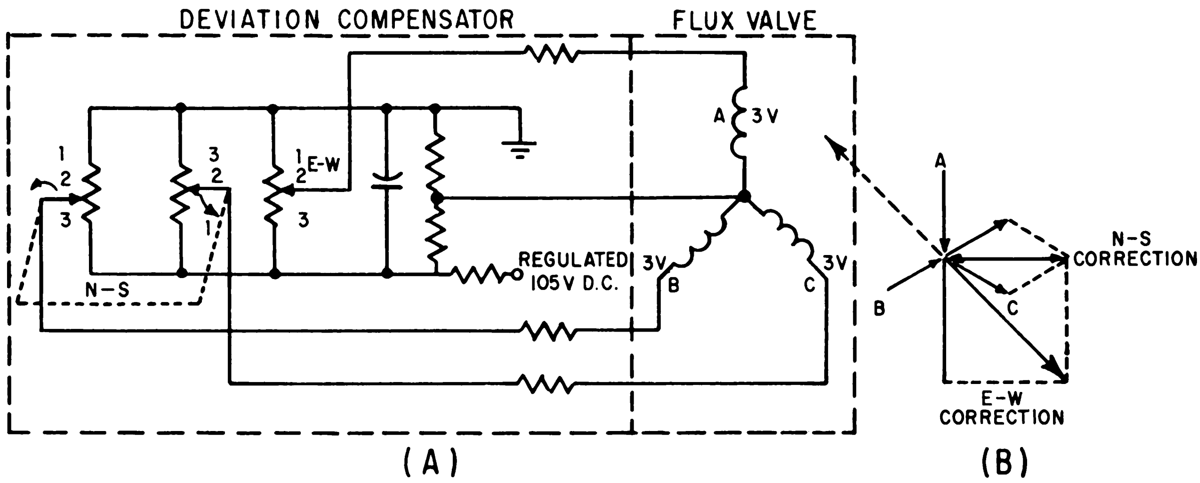


Figure 18-19.—(A) Magnetic deviation compensating circuit; (B) vector diagram of compensating magnetic field.

zero, no currents flow in the legs and no magnetic fields are developed. If one of the leg voltages is greater than the neutral voltage, current will flow in a direction away from the neutral point, setting up a field that could be represented by a vector adjacent to the leg and pointing away from the neutral. Also, if the leg voltage is less than the neutral voltage, the current and resultant field will be in the opposite direction.

Referring to figure 18-19 (B), assume that the magnetic field created by the aircraft is as represented by the heavy dashed arrow. An equal and opposite compensating magnetic field, represented by the heavy solid arrow, can be developed in the following way.

The N-S control is adjusted so that the voltage applied to leg C is greater than the neutral voltage, while simultaneously the voltage on leg B is made less than the neutral voltage. Also, the voltage on leg A is made less than the neutral voltage by adjusting the E-W control. In the field, these settings are arrived at by a standard compass swinging procedure; when correct, they will produce fields in legs A, B, and C as illustrated in figure 18-19 (B). The resultant of these three fields, represented by the heavy solid arrow, will exactly cancel out the magnetic field created by the aircraft.

MF-1 COMPASS SYSTEM

One of the latest compass systems in the field is the MF-1. It provides accurate directional information at all latitudes of the earth. The directional information is based on data provided from either a remote magnetic sensor, a roll stabilized directional gyro, or both, depending on the mode of operation. At latitudes where magnetic heading information is reliable, the remote magnetic sensor provides aircraft heading information based on the magnetic heading as a long term reference. This long term reference is used for correcting the highly accurate, short term, directional information furnished by the roll stabilized directional gyro. When the aircraft is in a geographical location where magnetic heading information is unreliable, only the directional reference from the roll stabilized gyro is used. The MF-1 compass uses three modes of operation as follows:

1. Magnetic mode.
2. Directional gyro mode.
3. Emergency mode.

The MF-1 system consists of a roll stabilized directional gyro (fig. 18-20), vertical gyro, compass servoamplifier, compass controller, roll stabilization controller, and a compass interconnection unit.

The MF-1 compass system is discussed in detail in Navy Training Course AE 1 & C, NavPers 10349-A.

MAINTENANCE AND TESTING

The maintenance and testing of gyrostabilized compass systems usually consists of voltage

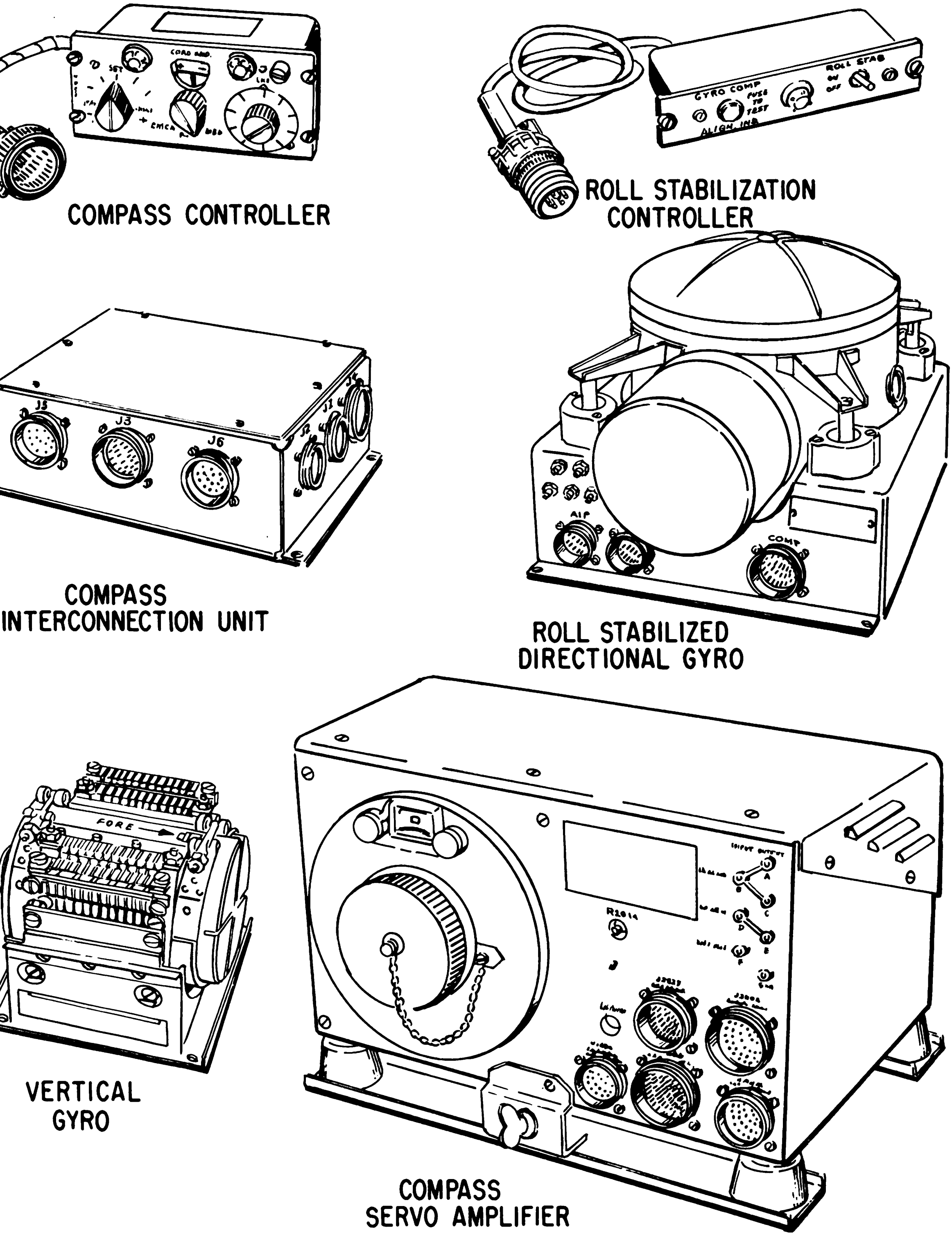


Figure 18-20.—MF-1 compass system components.

checks and operational tests of the various components. The correct voltages and voltage check points are given in the Maintenance Instructions Manual for the particular aircraft and also in the Operation and Service Instruction Manual for the compass.

To ground check a G-2 compass, check the system by offsetting the gyro element 10° on each side of the compass heading and timing its return. This should take about 4 minutes and the final heading should be identical with that of the correspondence indicator. Check all cardinal headings. The precession rates at large offsets should be 4° per minute.

The gyro is checked by placing the switch to FREE DG and noting the drift during 15-minute periods on the cardinal headings. The drift should not be over 4°, although one 6° drift is permissible if the total drift error is not over 16°.

The correspondence indicator and the transmitter act as a remote compass on the FREE DG setting. Some motion of the indicator will be noticed while turning the gyro, but this should not be permanent. With electrical power off, the indicator will revolve with the gyro since there is no restraint.

The method of compensating gyrostabilized compasses is the same as the method used for standby (magnetic) compasses. However, the compensating magnets are usually located on the remote compass transmitter. In some compass systems the compensating magnets are located on the amplifier or master directional indicator. To compensate the compass with the coefficient method, use a sighting compass or compass rose to aline the aircraft to the magnetic heading and use a standard correction card. For complete information on compass ground swinging with the coefficient method, refer to MIL-STD-765. This publication covers the general requirements governing the swinging of compasses in aircraft for compensation and calibration.

CHAPTER 19

AIRCRAFT INSTRUMENT SYSTEMS

When the first aircraft came into existence, the main objective was to launch the aircraft and keep it airborne as long as possible. At first, it was not possible to keep the aircraft in the air for longer than a few minutes. However, as better engines and aircraft structures were developed, the aircraft could remain aloft for a considerable length of time. Along with these improvements came the need for instruments. The first aircraft instruments were fuel and oil pressure instruments to warn of engine trouble so that the aircraft could land before the engine failed. Later, when the aircraft was able to fly over considerable distances, weather became a problem. This led to the development of instruments that helped to fly through snowstorms, thunderstorms, and other bad weather conditions. And so, as the need for various instruments became apparent, the development of aircraft instruments progressed.

Instruments that were used in aircraft a few years ago were reasonably simple as compared with those in current aircraft. The jet aircraft has brought many complex problems to instrument engineering.

Instrumentation is basically the science of measurement. Measurements that must be made in all aircraft are those that relate to position, direction, speed, altitude, engine condition, fuel on board, fuel consumption rate, and many others. In addition, jet aircraft instrumentation must indicate Mach number, angle of attack, tailpipe temperature, etc.

Along with the requirements of new aircraft for new and different instruments has come the demand for different cockpit configurations. In many aircraft the cockpit is smaller than usual, but the speed at which these aircraft operate has brought demands for increased readability, which has brought demands for larger size flight instruments in some cases. Compromises in size and panel placement and arrangement have become necessary. A trend in instrumentation is for smaller instruments, particularly those that are of secondary importance, such as hydraulic and pneumatic systems pressures, lubricating system pressures, and temperatures. A number of aircraft have 1 1/2-inch diameter pressure and temperature indicators. Also, some aircraft have only pressure and temperature limit indicators, similar to the landing gear position indicators.

There are two ways of grouping aircraft instruments. One is according to the job they perform. According to this classification, they fall into three classes—flight instruments, engine instruments, and navigation instruments. The other method of grouping aircraft instruments is according to the principles on which they work. Some operate in relation to changes in temperature or air pressure and some by fluid pressure. Others are activated by magnetism and electricity, and still others depend on gyroscopic action. In order to maintain instruments properly the AE must be well versed in basic hydraulic, mechanical, and gyroscopic principles. In addition, he must understand the electrical and electronic principles involved in aircraft instrument applications. Much of this information is available in the basic Navy Training Courses. Some of this information is presented in this chapter. A brief review of chapter 3 of this course would also be of benefit to the AE in studying this chapter.

PRESSURE

Force is the action of one body on another tending to change the state of motion of the body acted upon. Force may tend to move a body at rest, or it may tend to increase or decrease the motion of a moving body or change its direction of motion. The application of force may result in one or more of the

following stresses in the body acted upon: tension, pressure or compression, torsion, and shear.

A force can be measured in three ways: by the weight it can support, by its ability to stretch an elastic body, and by its ability to move a body. In physics, force is ordinarily measured in pounds or kilograms. Any force which changes the state of motion of a body is performing work upon that body. The amount of work accomplished is equal to the product of the force applied to the body and the distance through which it is moved, provided the displacement is in the direction of the force.

Pressure is force per unit area and is usually measured in pounds per square inch. For example, if the whole pull or push of an object is equal to 10 pounds, then the object is being acted upon by a total force of 10 pounds. Assume that a 10-pound force is pushing on one side of an object and that the push of this force is distributed evenly over the whole area of this particular side. (The side being pushed has an area of 10 square inches.) Since the force is divided evenly over this surface, each separate square inch of the side is being subjected to a force of 1 pound. Thus, 1 square inch is the unit area selected for the measurement of pressure. Since each square inch is being pushed by one-tenth of the 10-pound force—or 1 pound—the pressure is 1 pound per square inch. The unit of measurement selected here was pounds per square inch. Grams per square centimeter or tons per square foot could have been selected if it had been more convenient.

For some purposes another system for indicating pressure is often used. This system expresses pressure in inches of mercury and is discussed later in this chapter. The two types of pressure that are used in relation to aircraft instruments are atmospheric pressure and fluid liquid pressure. Instruments are operated by pressure, by vacuum, or by gyro.

ATMOSPHERIC PRESSURE

Before the AE can thoroughly understand some of the instruments used in an aircraft, he must know something about the earth's atmosphere—the layer of air that blankets the earth. This blanket of air that surrounds the earth is over 20 miles high.

If it was possible to have a vertical hollow tube 1 square inch in cross section and 20 or more miles in length, it would contain a definite mass of air. Beginning at the top of the tube at approximately zero pressure, each cubic inch of air would add its weight to the pressure on all cubic inches below it. The air pressure within the tube would then increase as measurements are made nearer the ground. At sea level the weight of the column of air is approximately 14.7 pounds. The pressure at the bottom is approximately 14.7 pounds per square inch. And again because pressure at a point in a fluid is transmitted equally in all directions, the pressure is 14.7 pounds per square inch on every square inch of surface at sea level regardless of its inclination to the vertical.

Actually, the air pressure becomes less and less as the altitude is increased. For this reason, an instrument called an altimeter, in an aircraft, is able to tell the pilot how high he is by measuring the air pressure and converting this air pressure to distance above the earth (altitude).

This leads to the basic instrument used for measuring air pressure—the barometer. The The simplest form of barometer is the mercury barometer shown in figure 19-1. It consists of

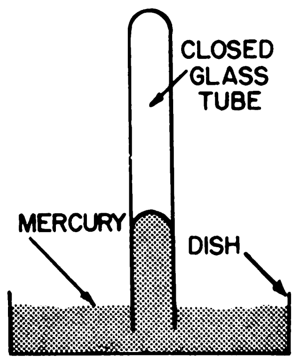


Figure 19-1.—Mercury barometer.

a glass tube that is closed at one end, some mercury, and a dish. The air has been pumped out of the closed tube and the tube has been immersed in the mercury. The air pressure pushing down on the mercury in the dish forces mercury up into the tube. At sea level and at 15° C, the mercury is forced up into the tube a distance of 29.92 inches. This is used as a measurement of air pressure (just like 14.7 pounds per square inch) and is called one atmosphere. It is called 29.92 inches Hg (Hg being the symbol for mercury).

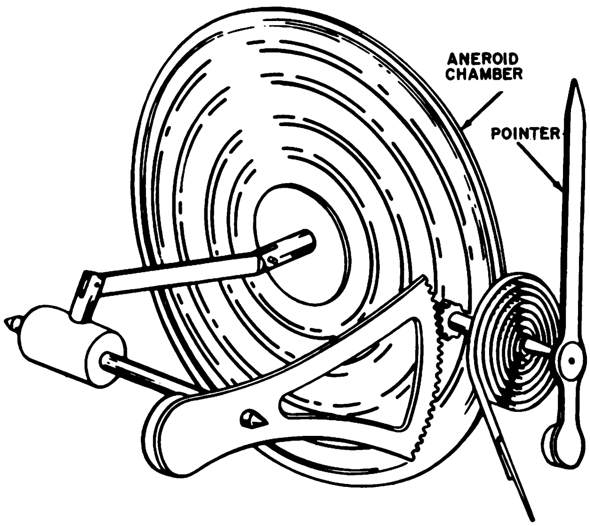


Figure 19-2.—Aneroid barometer.

ANEROID BAROMETER

The aneroid barometer (fig. 19-2) is portable and is much more practical than the mercury barometer. Its operating principles are as follows. The collapsible chamber or capsule is a corrugated metal box that is airtight. (Most of the air was removed from it before it was sealed shut.) One side of this capsule is fastened to the back of the barometer. The front of the capsule has a post fastened to it. This post is fastened by means of a linkage system to the gage pointer.

The dial on the aneroid barometer is calibrated so that when the mercury barometer reads 30 inches of mercury, the aneroid barometer reads 30.00. In an ascending aircraft, the air pressure would become less on the outside of the aneroid barometer capsule, and the capsule would expand. This expansion would cause a mechanical movement through the linkage so that there would be a different reading. The reading would depend upon the altitude; the higher the instrument the less the air pressure and thus a greater movement of the gage pointer. This is the basic principle of the altimeter, discussed later in this chapter. It converts air pressure to a reading of altitude in feet above the earth. The aneroid principle is also used in connection with rate of climb indicators; this is also discussed later in this chapter.

Aircraft instruments that use the aneroid chamber like the one in a barometer must be corrected for temperature changes, temperature lapse rates, and changes in humidity. Certain of these corrections are built into precision aneroid barometers by the incorporation of compensators when manufactured. Others must be accomplished by setting or adjusting the instruments as dictated by the existing weather conditions. These are discussed as the instruments are explained later in the chapter.

FLUID PRESSURE

A variety of aircraft instruments are operated by fluid pressure. In fluids, the pressure is the same in all directions at any point. If a surface is immersed in a stationary fluid, the pressure of the fluid is at right angles to the stationary surface. Some interesting things happen when a fluid is confined in a leakproof container. Under such conditions, an increase in pressure on any part of the confined fluid causes the same increase in pressure throughout the fluid. This is known as Pascal's principle. The pressure action within the container does not depend on its shape or on the fluid it contains so long as there is no loss of fluid.

Since an increase in pressure on any part of a confined fluid produces the same pressure throughout the fluid, then the application of a small force on a small area results in a much larger force on a large area.

This is the principle upon which a number of hydraulic mechanisms work. One example is in the hydraulic brake system of a modern automobile. The tubes, pistons, and cylinders which compose such a brake system are really an enclosed container filled with brake fluid. By pushing lightly on the brake pedal a small piston is operated thereby applying pressure on a small area of the fluid surface. The fluid immediately exerts a much greater force on the larger pistons operating the brake bands on each wheel. The force exerted on the larger piston is as many times greater than that exerted on the smaller as the area of the larger piston is greater than the smaller one.

The successful operation of current aircraft depends in many ways on fluid pressure systems. Pressure gages and other instruments are included in the fluid pressure systems to indicate their level of operation.

Direct reading pressure gages are connected into the particular systems for which they are designed by means of small pipelines. Each gage actually becomes a part of the "fluid container" of its system, and is supplied with a small quantity of fluid at the uniform system pressure.

One of the most practical methods of measuring fluid pressure is by using a Bourdon tube as the main part of the indicating device. The Bourdon tube is made of metal tubing that is oval or somewhat flattened. One end is closed; the other end has a fitting on it for connecting a pipeline. The connector end is fastened to the frame of the instrument, and the other end is free to move so that it can operate the mechanical linkage.

A simple Bourdon tube pressure gage is shown in figure 19-3. It operates in the following manner. Assume that it is used for measuring oil pressure and the oil line is connected at the left. The oil pump in the engine forces oil into the hollow curved tube. This causes the tube to try to straighten out, like a garden hose when the water is first turned on. As the movable end of the tube tries to turn outward, it turns the gear on the pivot. This gear meshes with the gear fastened to the indicator needle shaft and causes a reading on the pressure gage. The dial, which is not shown, is properly calibrated so that the needle points to the number which corresponds to the exact pressure. The tube acts like a spring. When the pressure is removed, it returns to its normal position.

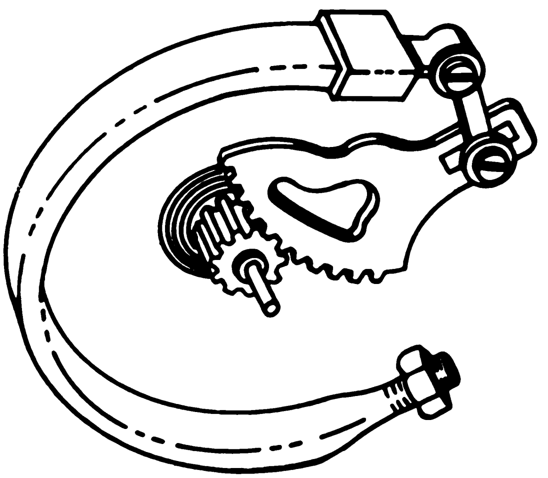


Figure 19-3.—Bourdon tube pressure gage.

A Bourdon tube is designed to measure a specific range of pressure, for example, from 0 to 300 or 0 to 3,000 psi. The tube material must be elastic and the dimensions such that the maximum pressure in the range of pressures to be measured does not strain or distort the material beyond its elastic limit. When this occurs the distortion is such that the tube will not resume its original shape after the pressure is relieved, resulting in erroneous readings. Thus Bourdon tubes designed to measure high pressures are made of heavy tubing and those designed for low pressures are made of thinner tubing. The two tubes may exhibit the same amount of movement when their rated pressures are applied, and will rotate the indicators through the same angles. The scales under the indicators are graduated to indicate the pressures applied.

AIRCRAFT PRESSURE GAGES

Pressure gages are used to indicate the pressure at which engine oil is forced through the bearings, oil passages, and moving parts of the engine and the pressure at which fuel is being delivered to the carburetor. They are also used to measure the pressure of air in deicer systems and gyroscope drives, of fuel mixture in the intake manifold, and of liquids or gases in a number of other systems.

ENGINE GAGE UNIT

The engine gage unit is what the name implies—three separate instruments housed in a single case (oil temperature gage, oil pressure gage, and fuel pressure gage). An engine gage unit is shown in figure 19-4.

Oil Temperature Gages

Two types of oil temperature gages are available for use in the engine gage unit. One unit consists of an electrical resistance type oil thermometer, supplied electrical current by the aircraft d-c power system. The other unit, the capillary oil thermometer, is a vapor pressure type thermometer consisting of a bulb connected by a capillary tube to a Bourdon tube and a multiplying mechanism connected to a pointer which indicates on a dial the temperature of the oil.

Oil Pressure Gages

Oil pressure instruments indicate that oil is or is not circulating under proper pressure. Oil

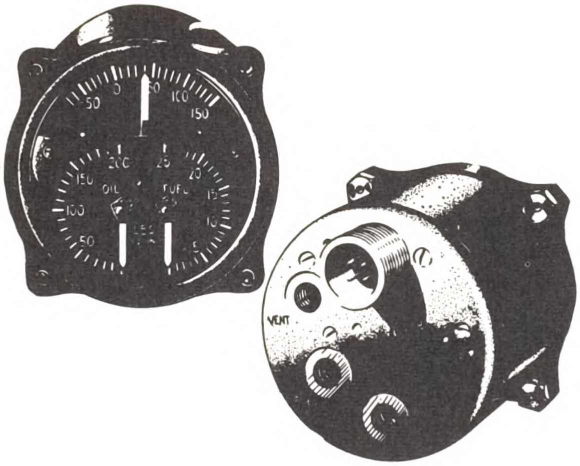


Figure 19-4.—Engine gage unit.

pressure drops warn of impending engine failure caused by lack of oil, oil pump failure, or broken lines. The gage has a Bourdon tube mechanism. (See fig. 19-3.) Its range is from 0 to 200 psi and its scale is marked in graduations of 10 psi. There is a single connection on the back of the case leading directly into the Bourdon tube.

Reciprocating aircraft engines are equipped with engine-driven oil pumps. Whenever the engine is running, oil is forced through the engine under pressure. This pressure is controlled by a pressure relief valve which can be set for the recommended pressure of the specific engine. The pressure gage is connected into the system at a point between the relief valve and the engine.

At the point where an oil pressure gage is connected into the system, there is a restriction in the line. This restriction prevents the surging action of the oil pump from damaging the gage, keeps the gage pointer from oscillating violently through wide ranges, and makes it possible to read the gage accurately. Because of this and the sluggishness of cold oil, the gage may fail to indicate any pressure immediately after the engine is started in cold weather; however, if the system is working properly, this will shortly correct itself.

When the gage does not respond, indicates incorrectly, or oscillates excessively, check all tubing and all tube connections throughout the system for pressure leaks. Tighten connections and replace the tubing if necessary. If the system is pressure tight, check the oil pressure with a direct-reading gage. If the pressure is correct, the fault is within the instrument. It should be removed and replaced with a serviceable one. Also, if there is excessive error at zero, the instrument should be replaced.

In some aircraft the oil pressure gage is a separate instrument; this type is shown in figure 19-5. This instrument operates on the same principle as the one previously explained.

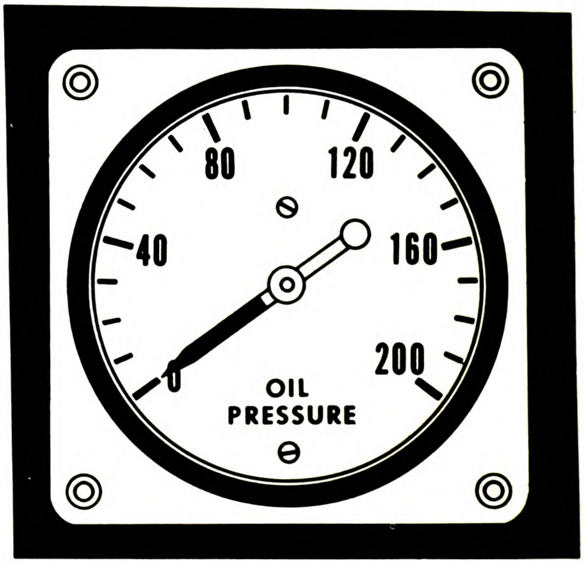


Figure 19-5.—Bourdon tube oil pressure instrument.

Fuel Pressure Gages

The fuel pressure gage (fig. 19-4) provides a check on the operation of the fuel pump and the fuel pressure-relief valve, and it indicates whether or not fuel is being supplied to the carburetor steadily under the correct operating pressure. In order to provide the full range of power at all altitudes, the gages must be checked often to insure that the fuel pressure is correct.

The fuel pressure gage operates on the same basic principle as the oil pressure gage.

MAGNESYN OIL PRESSURE SYSTEM

The Magnesyn oil pressure system used on some aircraft is essentially a method of measuring engine oil pressure directly, and transmitting the measurements electrically from the

point of measurement to the Magnesyn indicator on the instrument panel. The use of electrical transmission of measurement in the Magnesyn system eliminates the need for direct pressure lines from the engines to the instrument panel. Possibilities of fire hazard, loss of oil or fuel, and mechanical difficulties are greatly minimized.

The system is composed of two main units—the transmitter and the indicator. A transmitter is provided for each engine and is usually mounted on a bracket attached to the engine between the oil cooler and the air duct adapter near the top of the engine. An oil line connected to the engine oil system supplies pressure to the transmitter. Electrical current corresponding to the pressure of the system is relayed to the oil pressure gage (indicator) located on the instrument panel. The electrical leads between the transmitter and the indicator may be any reasonable length without noticeable effect on the indication.

Oil pressure Magnesyn transmitters are composed of two main parts—a bellows type mechanism for measuring pressure and a Magnesyn assembly. The pressure of the oil causes linear displacement of the Magnesyn magnet. The amount of displacement is proportional to the pressure. Varying voltages are set up in the Magnesyn stator, depending on the position of the magnet. These voltages are transmitted to the Magnesyn indicator which indicates on a dial the value received from the transmitter.

The indicator consists essentially of a Magnesyn, a pointer, and a graduated dial. The pointer is attached to the shaft of the magnet. Rotation of the magnet causes the pointer to move, indicating the value received from the transmitter. The indicator contains no brushes or sliding contacts. The only source of friction lies in the pivot jewels in which the rotor shaft (magnet) turns. The use of jewel pivots and a light rotor reduces friction to a minimum.

In some installations, dual indicators are used to obtain indications from two sources. Also, on some aircraft, both oil and fuel pressure transmitters are joined through a junction box and operate a Magnesyn oil and fuel pressure indicator (dual side-by-side), thus combining both gages within one case as shown in figure 19-6.

DEICING PRESSURE GAGES

The rubber expansion cells, which deice the leading edges of wings and stabilizers by expanding and breaking up the ice so that it can be blown away are operated by a compressed air system. The deicing system pressure gage measures the difference between the prevailing atmospheric pressure and the pressure inside the system, indicating whether there is sufficient pressure to operate the expansion cells. The gage also provides a method of measurement when setting the relief valve and regulator of the deicing system.

This instrument's case is vented at the bottom to keep the inside at atmospheric pressure as well as to provide a drain for any moisture which might accumulate. The pressure-measuring mechanism consists of a Bourdon tube and a sector gear with a pinion for amplifying the motion of the tube and transferring it to the pointer.

When installed and connected into an aircraft-deicing pressure system, the gage reading always remains at zero unless the deicing system is operating. When the system is in use and operating properly, the gage pointer fluctuates from 0 psi to its normal pressure reading because the expansion cells are periodically inflated and deflated. Do not confuse this normal fluctuation with oscillation, which is not a normal condition in any gage and must be corrected when it occurs.

SUCTION GAGES

Suction gages are used on aircraft to indicate the amount of suction that actuates the air-driven gyroscopic instruments. The spinning rotors of gyroscope instruments are kept in motion by streams of air which are directed against the rotor vanes. These airstreams are not produced by pumping air into the gyroscope instrument cases; instead, air is pumped out of them by the vacuum pump system. Atmospheric pressure then forces air into the cases through filters, and it is this incoming air that is directed against the rotor vanes to turn them.

The suction gage (fig. 19-7) indicates whether the vacuum pump system is working properly. A suction gage case is vented to the atmosphere or to the line of the air filter, and contains a pressure-sensitive capsule or diaphragm, plus the usual multiplying mechanism which amplifies the movement of the capsule's side and transfers it to the pointer. The pressure-sensitive capsule

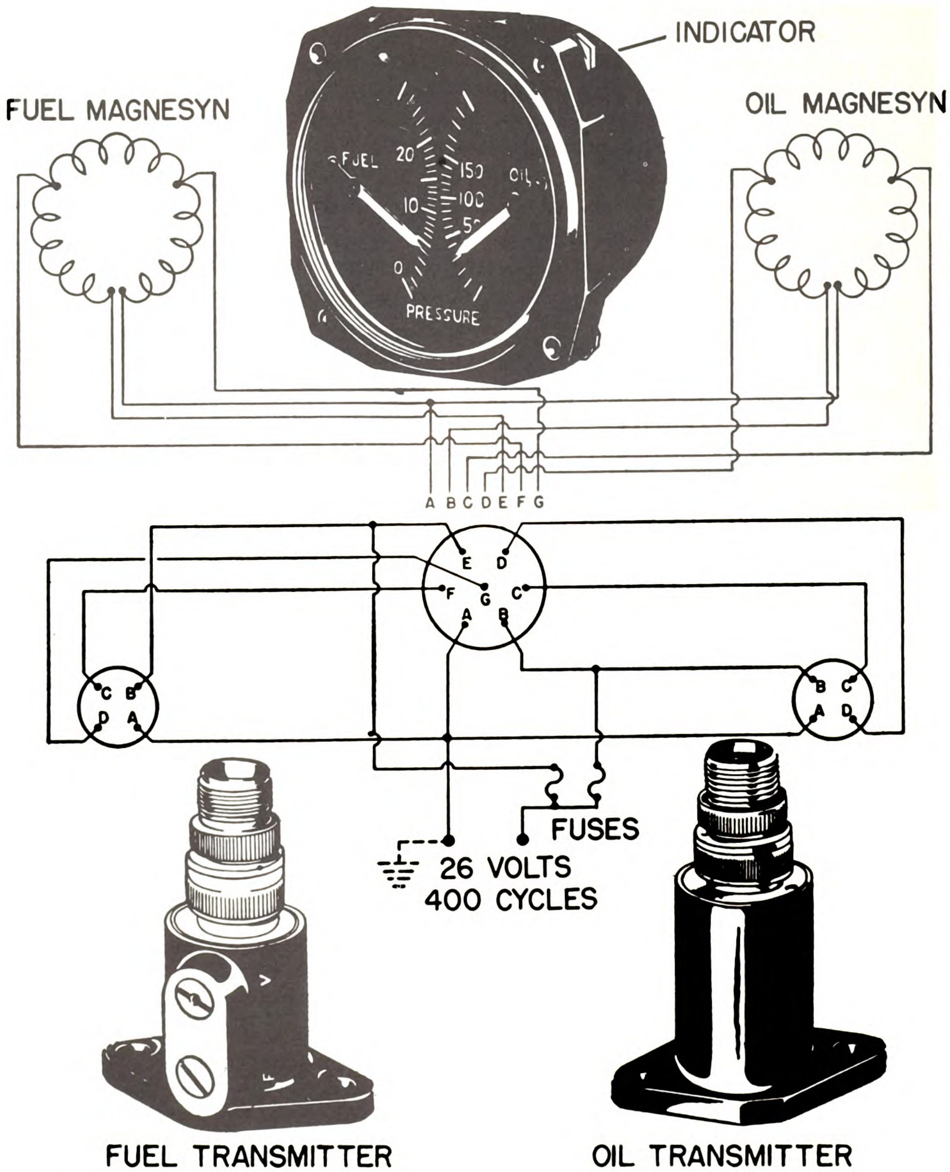


Figure 19-6.—Schematic of a dual Magnesyn system.

in a suction gage is similar to an aneroid capsule. However, it is not permanently evacuated and sealed, but is connected to the vacuum pump system through the back of the case—in much the same way that the Bourdon tube in a pressure gage is connected into a pressure system. The reading of a suction gage indicates the difference between atmospheric or filter system pressure and the reduced pressure in the vacuum pump system—in inches of mercury.

The gage has a range of 0 to 10 inches of mercury. The dial is graduated uniformly every 1 inch of mercury with numerals at 3, 4, and 5. The gage scale utilizes 300 degrees of the dial, with the first graduation representing 0 inch of mercury at the lower left-hand side. The gage pointer swings in a clockwise direction as the suction is increased, and it indicates pressure below the atmospheric pressure at the time the reading is taken. The gage pointer and numerals

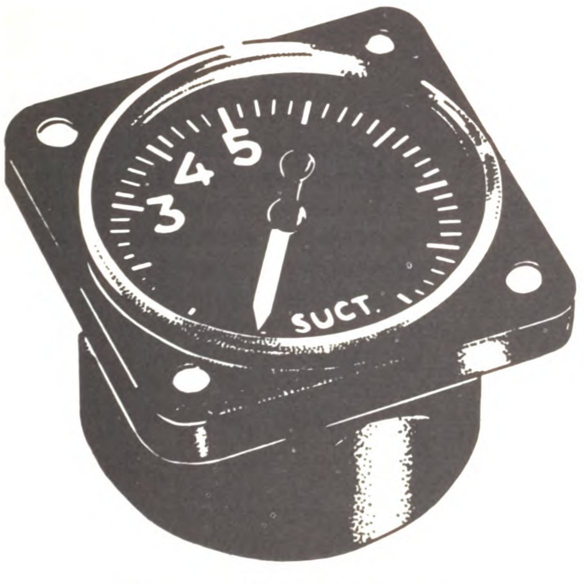


Figure 19-7.—Suction gage.

3, 4, and 5 are painted with a white luminous material which, under average night-flying conditions, will give sufficient luminosity to be readily legible. The normal suction gage reading is between 3.75 and 4.25 inches of Hg (mercury).

When connecting the suction gage into the vacuum system, clean the threads on the nipple and apply an antiseize compound. Tighten the connecting nut until the nipple seals properly, producing a tight joint but causing no excessive strain on the instrument.

If the suction gage is to be mounted on a vibration proof instrument panel and connected into another instrument on the same panel, the connecting tubing need not be flexible. But if the connecting tube is to be fastened to a rigid part of the aircraft, a flexible connection should be used.

HYDRAULIC PRESSURE GAGES

In most naval aircraft the hydraulic system operates the main landing gear, tailwheels, flaps, diving brakes, bomb bay doors, and certain other units. The aircraft hydraulic pressure gages are designed for use in the aircraft's hydraulic system to indicate the pressure of the complete system or the pressure of an individual unit in the system. A typical direct reading gage contains a Bourdon tube and a gear-and-pinion mechanism by which the tube's motion is amplified and transferred to the pointer. The position of the pointer on the calibrated dial indicates the pressure being measured in pounds per square inch.

The pumps which supply pressure for the operation of an aircraft's hydraulic units are driven either by the aircraft engine or by a separate electric motor, or by both. Some installations employ a pressure tank or "accumulator" to maintain a reserve of fluid under hydraulic pressure at all times. In such cases the pressure gage registers continuously. With other installations, however, operating pressure is built up only when needed, and pressure registers on the gage only during these periods.

The pressures of hydraulic systems vary for different models of aircraft. In older pressure systems the gages registered from 0 to 2,000 psi. In general, pressure ranges are increasing with the later models of aircraft. Some aircraft have systems with pressure ranges as high as 4,000 psi. The trend is away from the direct reading pressure gage and towards the synchro (electric) type.

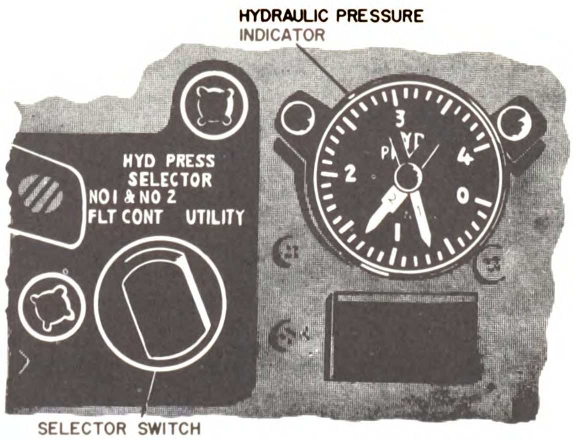


Figure 19-8.—Hydraulic pressure indicator.

Figure 19-8 shows the hydraulic pressure indicator of a late model naval aircraft. This aircraft is equipped with three hydraulic systems. The indicating system provides a continuous pressure indication of the No. 1 and No. 2 flight control systems and the utility hydraulic system. The indicating system consists of three remote pressure transmitters, one located in each of the system lines, a hydraulic pressure

selector switch and a dual pointer indicator, both located on the pilot's instrument panel. The system is powered by 26-volt, 400-cycle, single-phase alternating current from the 26-volt, single-phase bus.

A pressure transmitter of the Bourdon tube type is located in each hydraulic pressure system line. Expansion and contraction of the Bourdon tube is transmitted by mechanical linkage to the rotor of the transmitter synchro. The pressure transmitter synchro transmits an electrical signal through interconnecting wiring to the receiving synchro within the indicator. The receiving synchro's rotor is mechanically linked to the indicator pointer. The hydraulic pressure indicator contains two synchros mechanically attached to two separate pointers. When the HYD PRESS SELECTOR switch is in the No. 1 & No. 2 FLT. CONT position, the pointers indicate the pressure in each system independent of each other. When the HYD PRESS SELECTOR switch is in the UTILITY position, the synchros are connected in electrical parallel and the pointers act as one. An arrangement such as this is desirable since it saves instrument panel space.

MANIFOLD PRESSURE GAGES

The manifold pressure gage is an important instrument in an aircraft and is designed to measure absolute pressure. This pressure is the sum of the air pressure and the added pressure created by the supercharger. The dial of the instrument is calibrated in inches of mercury (Hg).

When the engine is not running, the manifold pressure gage records the existing atmospheric pressure. When the engine is running, it warns the pilot of oversupercharging at low altitudes and shows the loss of engine power when flying at high altitudes. It serves as a guide in adjusting the automatic controls on the supercharger.

Inside the instrument case is an evacuated aneorid capsule and a multiplying link mechanism which connects the aneroid to the pointer. The manifold system pressure is introduced into another diaphragm capsule through a connection at the back. This pressure inlet is fitted with a restrictor, which keeps foreign matter from entering the instrument and helps to smooth out any rapid fluctuations of pressure that may be transmitted from the manifold. A cutaway view of a typical manifold pressure gage is shown in figure 19-9.

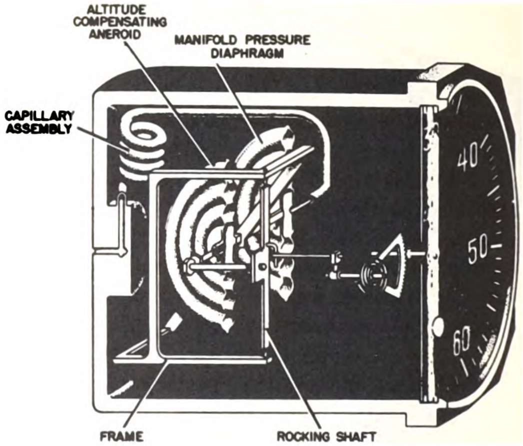


Figure 19-9.—Cutaway view of a manifold pressure gage.

One type of manifold pressure gage indicates absolute pressures within a range of 10 to 70 inches Hg. Another type has a range of 25 to 60 inches Hg. A third type has a range of 10 to 50 inches Hg. The dials of all types are graduated in increments of 1 inch Hg, with numerals at each 10-inch interval on the scale.

The readings obtained on a manifold pressure gage depend on engine speed throttle position and supercharger characteristics. One kind of supercharger—the internal geared type—is the induction system between the carburetor and the cylinder intake ports. With this supercharging system, the gage registers the pressure between the supercharger outlet and the cylinder intake ports. When an external or exhaust-driven supercharger is added to the system, the carburetor is between the supercharger and the cylinder intake ports. In this case the gage is connected into the system at a point prior to where the fuel mixture enters the engine.

The manifold pressure gage indicates the manifold pressure immediately before the cylinder intake ports. The gage though ruggedly constructed is very sensitive. However, it will stand up under the vibration received during normal use. (This does not mean it can be given rough treatment and remain accurate.)

The correct manifold pressures for takeoff, climbing, diving, and cruising vary with each kind of engine. This information may be found in operating instruction manuals for the particular engine.

When installing a manifold pressure gage on the instrument panel, make sure that the pointer is vertical when registering approximately 30 inches Hg. A length of flexible tubing about 10 inches long should be connected between the instrument and the rigid tube, which extends to the connection point on the manifold.

When an engine is not running, the manifold pressure gage reading should be the same as local barometric pressure. Check it against an accurate barometer such as the altimeter in the cockpit. With the aircraft on the ground, set the altimeter hands to station pressure altitude, and tap the instrument panel lightly a few times to remove frictional errors. There is a barometer scale on the altimeter, and with the altitude hands at station pressure altitude this scale will show local atmospheric pressure in inches of mercury. The manifold pressure gage should agree with this pressure within 0.4 inch Hg.

After starting the engine, open the drain cock for about 30 seconds with the engine idling. This will clear the gage line of moisture that may have condensed and collected in it. After the drain cock is closed and the engine is allowed to continue idling, the manifold pressure reading will go down as low as 10 to 15 inches Hg. Do not be concerned about this for it is normal for the pressure to drop at engine idling speed. It will rise when the engine speed is increased.

Movement of the pressure gage pointer should be slow and steady. Rapid movement or oscillation is an indication that the damping adjustments are not operating properly or that there is a leak in the line or case. The case may be tested for leaks by disconnecting the line at the engine and applying air pressure until the gage indicates 50 inches Hg, then close the line. A leak is present if the gate pointer returns to atmospheric pressure.

To check on proper adjustment of the damping restrictor, release the pressure suddenly when the gage reads 50 inches Hg. The pointer should reach 32 inches Hg in not less than 1 1/2 seconds, and not more than 2 1/2 seconds.

Some engines are equipped with a Magnesyn manifold pressure gage. This gage is also for measuring the absolute pressure of the fuel and air mixture as it enters the intake manifold. The measurement is transmitted electrically from the point of measurement to the Magnesyn indicator on the instrument panel. The operation of this type system is similar to other Magnesyn systems that have been explained in this chapter and will not be repeated.

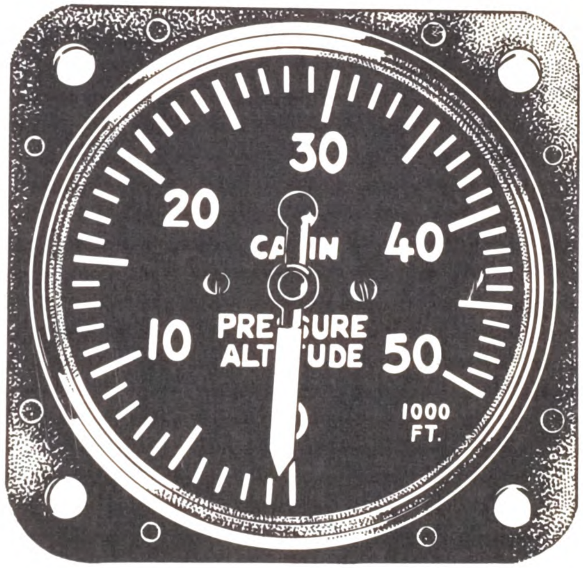


Figure 19-10.—Cabin pressure altitude indicator.

CABIN PRESSURE GAGES

The cabin pressure altitude indicator (fig. 19-10) is a sensitive altimeter used to measure the cabin pressure. The instrument contains a sensitive diaphragm which expands or contracts with changes in cabin pressure. The altitude equivalent of cabin pressure is indicated on the dial in increments of 1,000 feet within the range from 0 to 50,000 feet. An opening in the back of the case permits sensing of the cabin pressure. The instrument may be used to reflect pressure suit altitude rather than cabin altitude when a pressure suit is worn.

The cabin pressure altitude indicator should be removed if the aircraft is to undergo a cabin pressurization test on the ground. Failure to remove the indicator will result in damage to the instrument due to excessive pressure.

TORQUE PRESSURE INDICATOR

The torque pressure indicating instrument is used to give an accurate measurement of the actual power output to the propellers of a reciprocating engine when the engine is operating.

The torque force of the engine that is normally absorbed by the stationary gear of the reduction gearing system of the engine is utilized to measure the crankshaft output in terms of oil pressure. As the torque force is increased, the movement of the reduction gear allows high pressure oil from a torquemeter booster pump located on the engine, to be metered to the torquemeter mechanism on the engine.

The torquemeter transmitter is connected to the torquemeter mechanism on the engine by a flexible hose. The transmitter is provided with a snubber which prevents pressure surges of oil from affecting the transmitter which would in turn result in indicator pointer fluctuation.

The transmitter converts the applied oil pressure to an electrical signal output which is then sent to the indicator. The transmitter operates on a Bourdon principle which rotates a shaft when the applied oil pressure causes the tube to change shape. The movement of the shaft is transmitted electrically to the indicator which in turn rotates to cause the pointer to indicate.

The torque pressure indicator has a range of 0 to 50 psi (multiples of 10) as shown in figure 19-11.

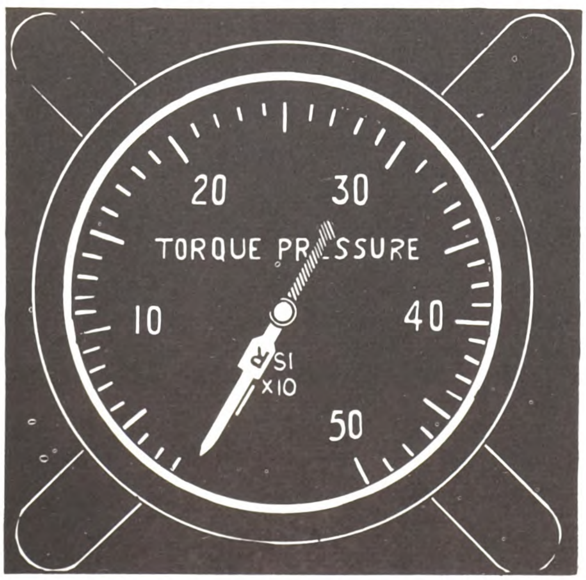


Figure 19-11.—Torque pressure indicator.

An operation check of the torque pressure indicating system is made with the engine operating at a given tachometer (rpm) indication with the manifold pressure adjusted to a predetermined setting. Refer to the Maintenance Instructions Manual of the squadron aircraft for complete information on operational setting for the torque indicating system in an aircraft.

Figure 19-12.—Accelerometer.

ACCELEROMETER

The accelerometer (fig. 19-12) furnishes an indication of the load on the structure of the aircraft in terms of gravitation (g) units. It presents information which enables the aircraft to be maneuvered within its operational limits. The pilot must limit the maneuvers of the aircraft so that various combinations of acceleration, airspeed, gross weight, and altitude remain within the specified values, thereby eliminating the possibility of damage to the aircraft as a result of excessive stresses.

The forces sensed by the accelerometer act along the vertical axis of the aircraft. The main hand moves clockwise as the aircraft accelerates upward; it moves counterclockwise as the aircraft acclerates downward.

The indications shown by the accelerometer are in g units. The main indicating hand turns to +1 g whenever the lift of the aircraft wing is exactly equal to the weight of the aircraft. Such a condition prevails in level flight. The hand turns

to +3 g when the lift is three times the weight; or to minus readings when the forces acting on the aircraft surfaces cause the aircraft to accelerate downward.

The accelerometer operates independently of the other aircraft instruments and installations. The activating element of the mechanism is a mass that is movable in a vertical direction on a pair of shafts. Vertical movement of the mass is damped by the action of a spiral-wound main spring. The force of the mass is transmitted by means of a string and pulley system to the main spring and main shaft and to the plus and minus assemblies, on which are mounted the hand assemblies. Changes in vertical acceleration cause movement of the mass on the shafts, which is translated into turning motion of the main shaft. The turning motion pivots the indicating hands around the dial a distance equivalent to the value in g units of the upward or downward acceleration of the aircraft. (See fig. 19-13.)

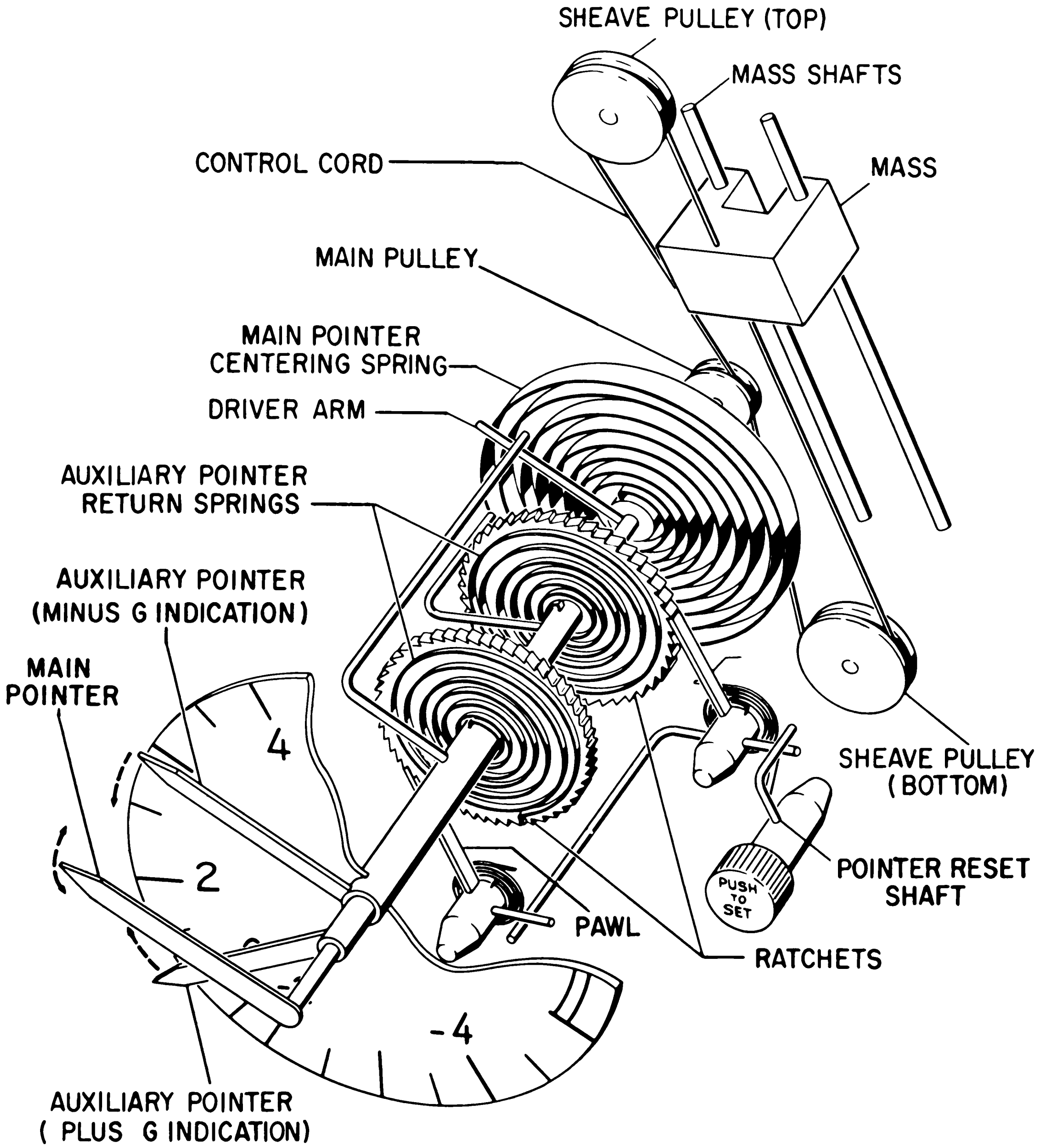


Figure 19-13.—Accelerometer mechanical schematic.

The accelerometer operates on the principle that bodies in motion tend to remain in motion and bodies at rest tend to remain at rest unless an external force acts on the body. During level flight, no forces act on the mass to displace it from a position about midway between the top and bottom of the mass shafts. Consequently the accelerometer pulley system performs no work and the indicating hands remain stationary at +1 g. When the aircraft changes from level flight, forces act on the mass causing it to move either above or below its midway position. These movements cause the accelerometer indicating hands to change their position. When the aircraft goes into a dive, the hands move to the minus section of the dial; when it begins to climb, they move to the plus section.

The main hand continuously indicates changes in loading. The two other hands on the accelerometer indicate the highest plus acceleration and highest minus acceleration of the aircraft during any maneuver. These readings are maintained through the use of a ratchet mechanism. A knob in the lower left of the instrument face provides a means for resetting the maximum- and minimum-reading hands to normal at any time. Thus, the accelerometer may retain an indication of the highest plus and minus accleration during a particular phase of a flight or during a series of flights.

COUNTING ACCELEROMETER

Some new aircraft such as the F-8E and A-6A are equipped with counting accelerometers. The counting accelerometer system indicates and records the maximum accelerations of the aircraft during a flight. The system records the number of times the preset airframe gravitational loads are equaled or exceeded.

The system consists of a sensor and an indicator. The sensor consists of a movable mass that changes the positions of a contact bar. As the contact bar moves across successive contacts, a signal is generated which operates relays in the indicator. Signals from the sensor activates one or more of the four indicator counters, which are individually preset to register loads of 4 g, 5 g, 6 g, and 7 g. For example, a maneuver that produces a 5 g load on the aircraft causes one unit to be registered on the No. 1 and No. 2 counters. A 7 g (or higher) load maneuver causes one unit to be registered on each of the four counters. A 4 g (but less than 5 g) load causes one unit to be registered only on counter No. 1. The indicator provides a cumulative total of the number of times the g loads (4 g, 5 g, 6 g, or 7 g) have been equaled or exceeded.

The accelerometer indicator has four counter windows from which readings can be taken when the aircraft is on the ground. The counting accelerometer system is operated by 28 volts d.c. from the secondary bus through the up and locked contacts of the main gear up switch.

The location of the indicator and sensor vary with different aircraft configurations. On a typical installation such as the F-8E, the indicator and sensor are located in the right-hand main gear well.

(A counting accelerometer reading report must be submitted to BuWeps each month on NavWeps Form 13920/1. Refer to BuWeps Instruction 13920.1 for procedures and policies governing this report.)

AIR PRESSURE MEASURING INSTRUMENTS

PITOT-STATIC SYSTEM

The pitot-static system in an aircraft includes some of the instruments that operate on the barometer principle. It consists of a pitot-static tube and three indicators, all connected with pipelines that carry air. The three indicators are the airspeed indicator, the altimeter, and the rate-of-climb indicator. The airspeed indicator indicates the speed of the aircraft through the air; the altimeter indicates the altitude; and the rate-of-climb indicator indicates how fast the aircraft is climbing or descending. They all operate on air that is taken in from outside the aircraft during flight. By referring to figure 19-14, the interrelationship of the pitot-static tube, the airspeed indicator, the altimeter, and the rate-of-climb indicator can be seen.

Pitot stands for impact pressure, which is the pressure of the outside air rushing against the aircraft flying through it. The tube or line that goes from the pitot chamber of the pitot-static tube to the airspeed indicator merely applies the pressure of this outside air to the airspeed indicator. The airspeed indicator is calibrated so that different air pressure causes different readings on the dial. In other words, the airspeed indicator interprets air pressure from the pitot tube in terms of airspeed in knots.

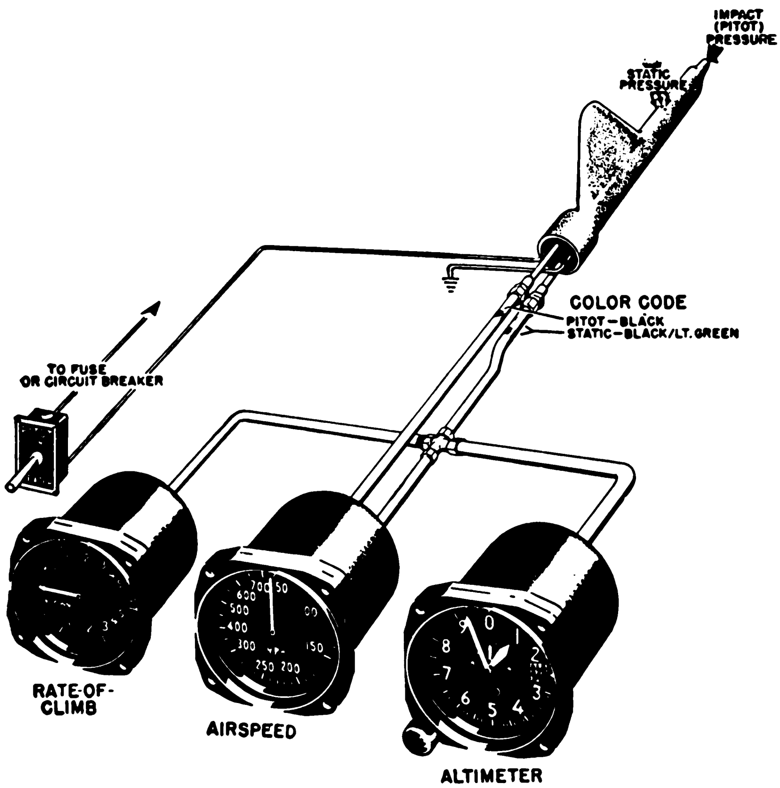


Figure 19-14.—Pressure measuring instruments.

Static means stationary or not changing. The static part of the pitot-static system (fig. 19-15) introduces outside air also but at its normal outside atmospheric pressure as though the aircraft were standing still in the air. The static line applies this outside air to the altimeter, the rate-of-climb indicator, and the airspeed indicator.

A pitot-static tube is shown in figure 19-16. The tube is made of brass or chrome-plated copper, and is divided into two sections. The forward end of the tube is open at the front to admit the outside air. The pitot tube or pressure tube leads backward to the pitot chamber in the "shark fin" projection near the rear of the assembly. A riser or upright tube leads the air from this chamber to the airspeed indicator and provides insurance against fouling the system with ice, dirt, or water. The tubes are provided with heating elements to prevent icing during flight. These elements are sturdy and not likely to burn out during the life of the tube. The tubes must be kept clean at all times. When the aircraft is not flying, its airspeed tube should be covered by a sack made of a suitable material (lint-free cloth or leather).

The static chamber of the pitot-static tube is pierced by small openings or static holes on the top and bottom surfaces. These openings are designed and located so that this part of the system provides accurate measurements of atmospheric pressure in a static or still condition. The static chamber also contains a riser tube, which leads to the altimeter, rate-of-climb indicator, and the airspeed indicator.

The tube is mounted on the outside of the aircraft at a point where the air is least likely to be turbulent, and points in a forward direction parallel to the aircraft's line of flight. One general type of airspeed tube is designed for mounting on a streamlined mast extending below the nose of the fuselage. Another type is designed for installation on a boom extending forward of the leading edge of the wing. Although there is a slight difference in their construction, actually they operate identically.

On the back of an airspeed or rate-of-climb indicator, the words "Do not blow in tubes"

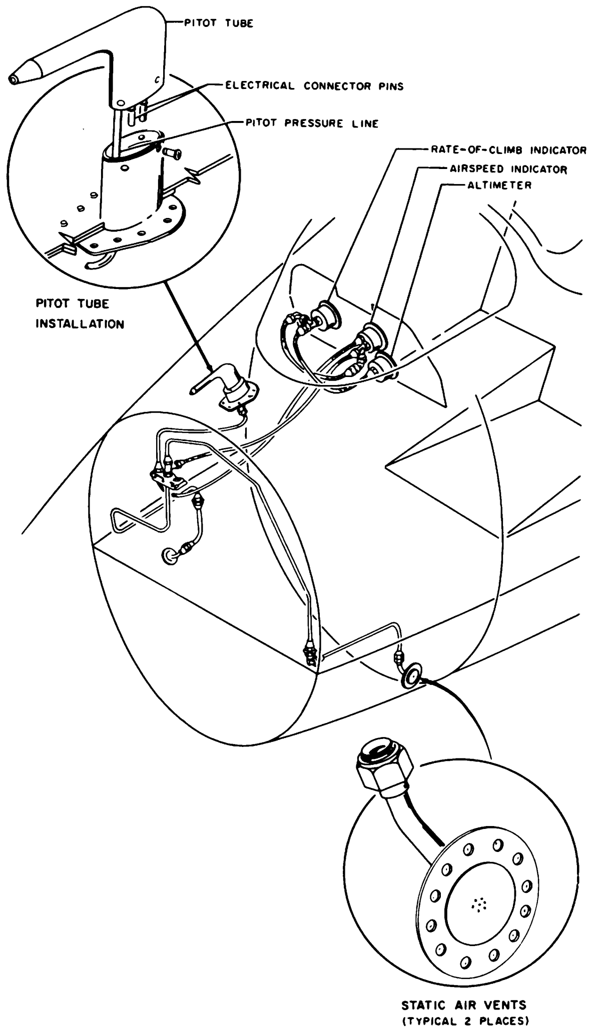


Figure 19-15.—Pitot-static system.

are inscribed. Always remove all instruments before cleaning the lines. The number of indicators per aircraft that can be damaged depends on the model (small aircraft, 3 instruments; larger aircraft, 10 or 12 instruments). Only clean dry filtered air should be circulated through the complete pitot-static system after all the instruments have been disconnected and both the pitot and static line drain caps have been removed. Air should also be circulated through each static vent of the system being careful not to include the cabin pressurization system static vent as part of the pitot-static system. Replace all drain line caps and reconnect all instruments before the pressure check. The pressure check is of the utmost importance as a slight leak will result in erroneous indications of the instruments during flight (also check pitot heat: touch system or voltage drop). The following steps are outlined for possible use by the AE as the proper procedure for water and debris removal from the pitot-static system.

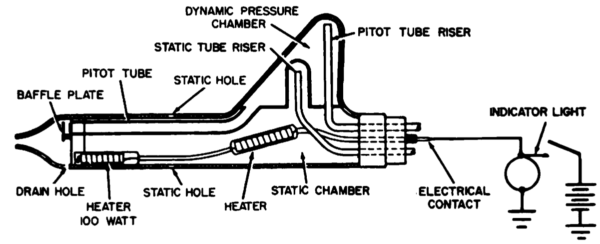


Figure 19-16.—Pitot-static tube.

1. Disconnect all altimeters and airspeed and rate-of-climb indicators on the aircraft. Disconnect the lines from the pitot or pitot-static tubes.
2. Remove all drain caps in the system. (Refer to the Maintenance Instructions Manual for location.)
3. Circulate a stream of clean, dry, filtered air at medium pressure through the complete system and into each static vent being careful not to include the cabin pressurization system static vent. Be certain that air is flowing from the exit end of each line.
4. Inspect all static vents and the pitot tube water removal drain holes for damage and evidence of foreign matter and obstructions. Check all low points in the lines for possible cracks due to previous icing of water in the lines.
5. Replace and secure all system drain caps.
6. Reconnect all instruments. For proper installation refer to the Maintenance Instructions Manual. Tighten connections properly, avoiding kinking or bending the lines.
7. Using a field test set or other approved tester, thoroughly check the system for proper operation and leaks. While the pitot-static system is relatively simple when compared to the more complex systems, its maintenance should not be considered a minor task. Remember, in the event of electrical or engine failure or malfunction a pilot will need these primary flight indicators to effect a successful landing.

AIRSPEED INDICATORS

The airspeed indicator is useful in a number of ways. Its readings are important when estimating groundspeed and in determining throttle

settings for the most efficient flying speed. It also provides a basis for calculating the best climbing and gliding angles. It warns when diving speed approaches the safety limits of the aircraft's structure. And, since airspeed increases when the nose drops and decreases in a climb, the indicator is an excellent check on whether level flight is being maintained. Figure 19-17 shows a cutaway view of a typical airspeed indicator.

An airspeed indicator has a cylindrical airtight case, which is connected to the static line from the pitot-static tube. Inside the case is a small aneroid diaphragm that is made of phosphor bronze or beryllium copper. The diaphragm, which is very sensitive to changes in pressure, is connected to the impact pressure (pitot) line so that air from the pitot tube can enter the diaphragm. This side of the diaphragm is fastened to the case and is rigid. The needle or pointer is connected through a series of levers and gears with the free side of the diaphragm.

The airspeed indicator is a differential pressure instrument. That is, it measures the difference between the pressure in the impact pressure line and the pressure in the static pressure line. The two pressures are equal when the aircraft is stationary on the ground. However, movement through the air causes the pressure in the impact line to become greater than the pressure in the static line. The diaphragm, being connected directly to the impact pressure line, expands because of this increase in impact pressure. The expansion or contraction of the diaphragm is transmitted by a series of levers and gears to the face of the instrument to regulate the position of the needle. The needle indicates the pressure differential in mph or knots. (All speeds and distances are based on nautical miles.)

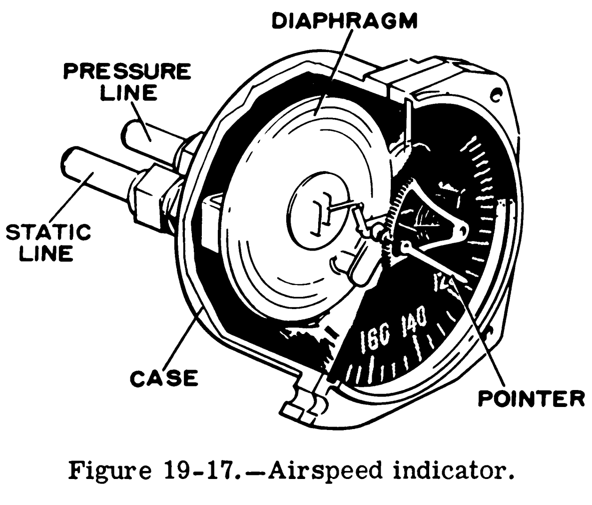


Figure 19-17.—Airspeed indicator.

In the interest of obtaining accurate readings from an airspeed indicator, it should be remembered that errors are usually the result of installation conditions or of poor adjustments on the instrument.

No matter how carefully the location is chosen for placing the pitot-static tube on the aircraft, it is almost impossible to keep it free from all air disturbances set up by the aircraft structure. Actually, the differential pressure developed in the pitot-static system is slightly different than it would be if conditions were theoretically perfect. Allowances must be made when reading the indicator for this "installation error." Errors may also be caused by temperature changes in the instrument or by imperfect scaling of the indicator dial with respect to the airspeed-differential pressure relationship. Rather simple adjustments can be made in the instrument mechanism itself to correct the tendency of the instrument to read fast or slow.

MACH NUMBER INDICATORS

In some instances the speed of an aircraft is expressed in terms of Mach numbers rather than in mph or in knots. The Mach number of any moving body is the ratio of its speed to the speed of sound in the surrounding medium (local speed). For example, if an aircraft is flying at a speed equal to one-half the local speed of sound, it is said to be flying at Mach 0.5. If it moves at twice the local speed of sound, its speed is then Mach 2. (The term Mach number is derived from the name of an Austrian physicist, Ernst Mach, who was a pioneer in the field of aerodynamics.)

Figure 19-18 shows the front view of a typical airspeed and Mach number indicator. The instrument consists of altitude and airspeed mechanisms incorporated in a single housing. It provides the pilot with a simplified presentation of both indicated airspeed and Mach number. Both indications are read from the same pointer. The pointer indicates airspeed at low speeds, and both indicated airspeed and Mach number at high speeds. The pointer is moved by pitot pressure on a diaphragm, and the Mach number dial is controlled by an aneroid diaphragm which reacts to static pressure changes due to altitude changes. Figure 19-19 is a mechanical schematic of an airspeed and Mach indicator.

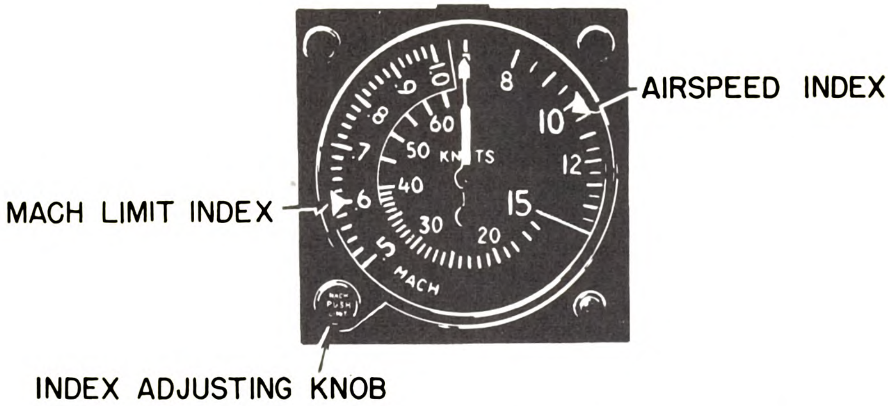


Figure 19-18.—Airspeed and Mach number indicator.

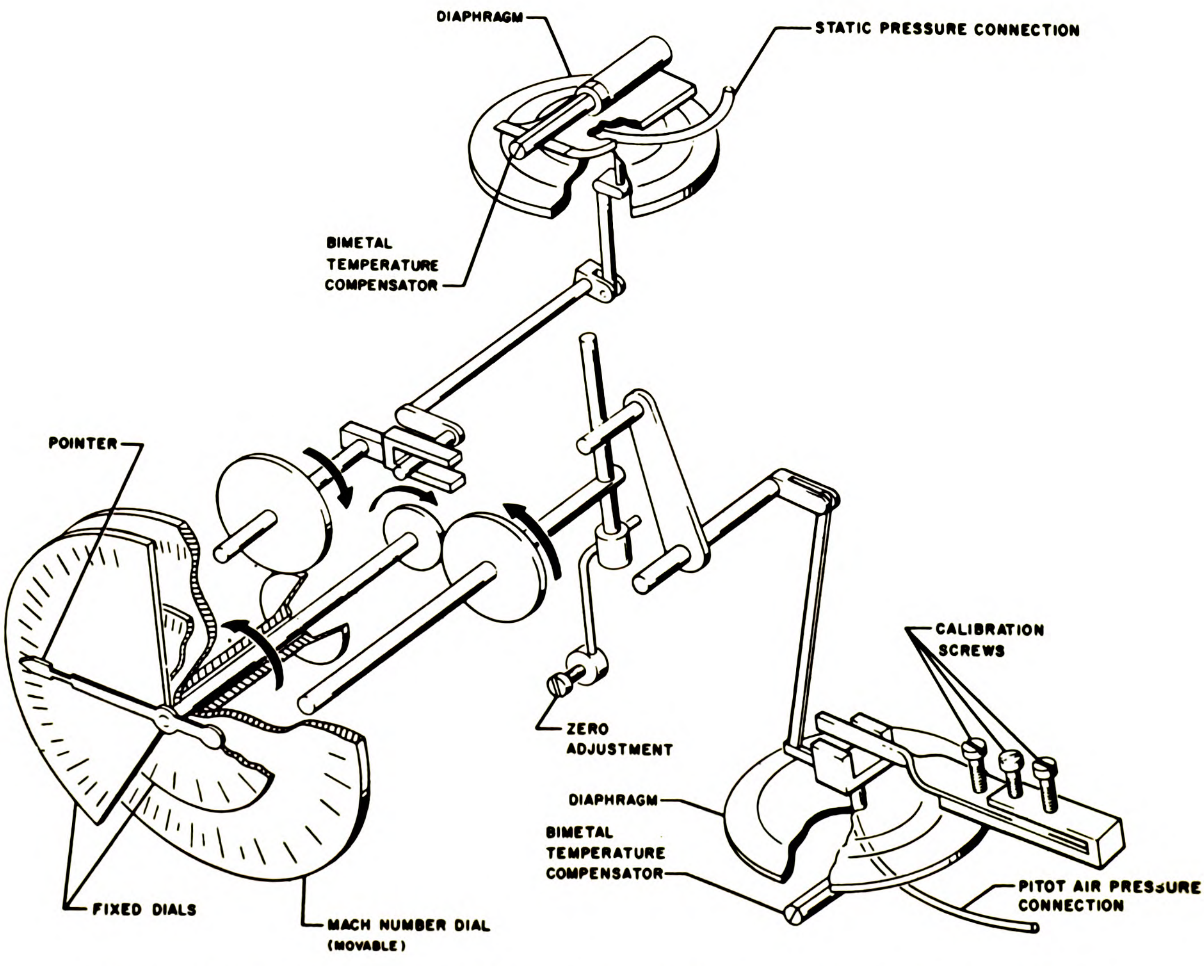


Figure 19-19.—Airspeed and Mach number indicator mechanical schematic.

The range of the instrument is 80 to 650 knots indicated airspeed and from 0.5 to 2.0 Mach number, with a calibrated operating limit of 50,000 feet of altitude. The upper range of the movable Mach dial is masked by the stationary airspeed dial at low altitudes. The stationary airspeed dial is graduated in knots. The instrument incorporates a landing speed index and a Mach number setting index. Both indexes can be set manually by a knob located on the lower left-hand corner of the instrument. The landing speed index can be set over a range of 80 to 150 knots and is operated with the knob in its normal position. The Mach number index can be set over the entire Mach range and is operated by depressing the knob and turning it.

ALTIMETERS

There are many kinds of altimeters in general use today. However, they are all constructed on the same basic principle as an aneroid barometer. They all have pressure-responsive elements (aneroid wafers) which expand or contract with the pressure changes of different flight levels. The heart of an altimeter is its aneroid mechanism (fig. 19-2), which consists of one or more aneroid wafers. The expansion or contraction of the aneroid wafers with pressure changes actuates the linkage, and the indicating hands show altitude. Around the aneroid mechanism of most altimeters is a device called the bimetal yoke. As the name implies, this device is composed of two metals and performs the function of compensating for the effect that temperature has on the metals of the aneroid mechanism.

The dial face of the typical altimeter is graduated with numerals from 0 to 9 inclusive, as shown in figure 19-20. Movement of the aneroid element is transmitted through a gear train to the three hands on the instrument face. These hands sweep the calibrated dial to indicate the altitude of the aircraft. The shortest hand indicates altitude in tens of thousands of feet; the intermediate hand, in thousands of feet; and the longest hand, in hundreds of feet in increments of 20 feet. A barometric scale, located at the right of the instrument face, can be set by a knob located at the lower left of the instrument case. Since atmospheric pressure continually changes, the barometric scale must be reset to the current station altimeter setting before the altimeter can indicate the correct altitude of the aircraft above sea level. When the setting knob is turned, the barometric scale, the hands, and the aneroid element move to aline the instrument mechanism with the new altimeter setting.

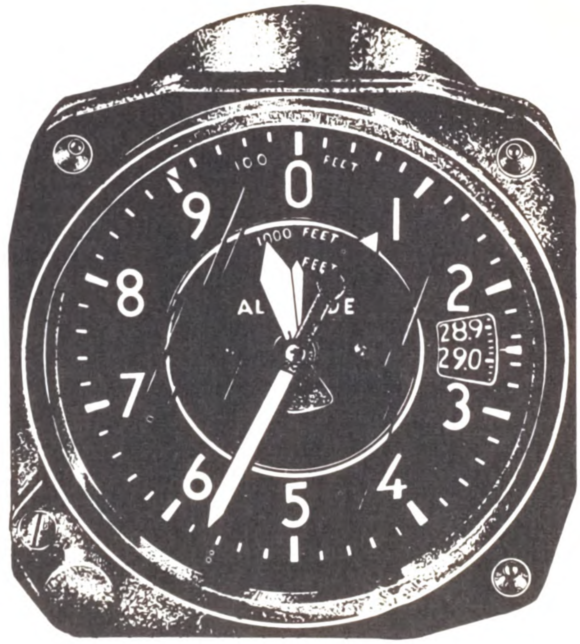


Figure 19-20.—An altimeter dial.

The mechanism of a sensitive altimeter, such as the one shown in figure 19-20, is shown in figure 19-21. The movement of the aneroid diaphragm is linked to a rocking shaft, causing the shaft to turn. The sector, attached to the rocking shaft, engages a pinion and gear, causing movement of the indicator hands over the face of the dial.

Counter Pointer Pressure Altimeter

An altimeter that is quite different from the conventional one just described is shown in figure 19-22. This is a counter pointer pressure altimeter and is designed to indicate the height of an aircraft. By studying the dial of the indicator it is easy to understand the procedure for determining the height of the aircraft. A description of the mechanical operation of this altimeter follows.

Atmospheric changes cause movement of the two aneroid diaphragm assemblies (1, fig. 19-23) which is transferred to two similar rocking shaft assemblies (2) mutually engaged with the main pinion assembly (3). This movement is transmitted to the handstaff assembly (4) which

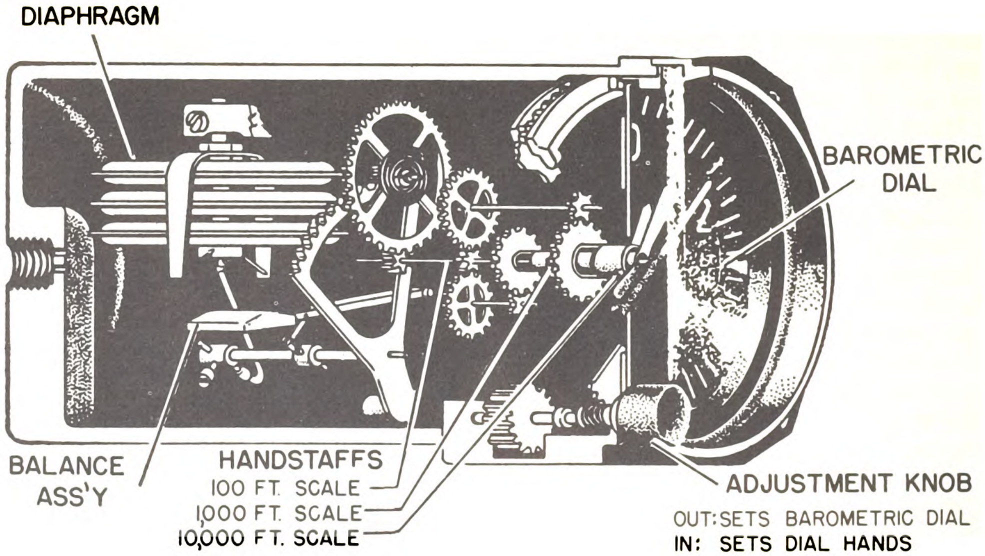


Figure 19-21.—Mechanism of a sensitive altimeter.

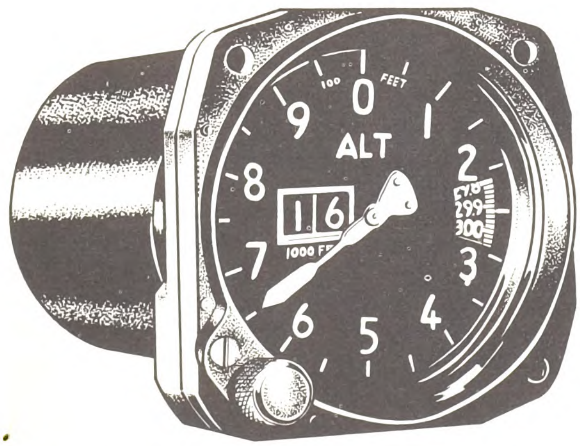


Figure 19-22.—Counter pointer pressure altimeter.

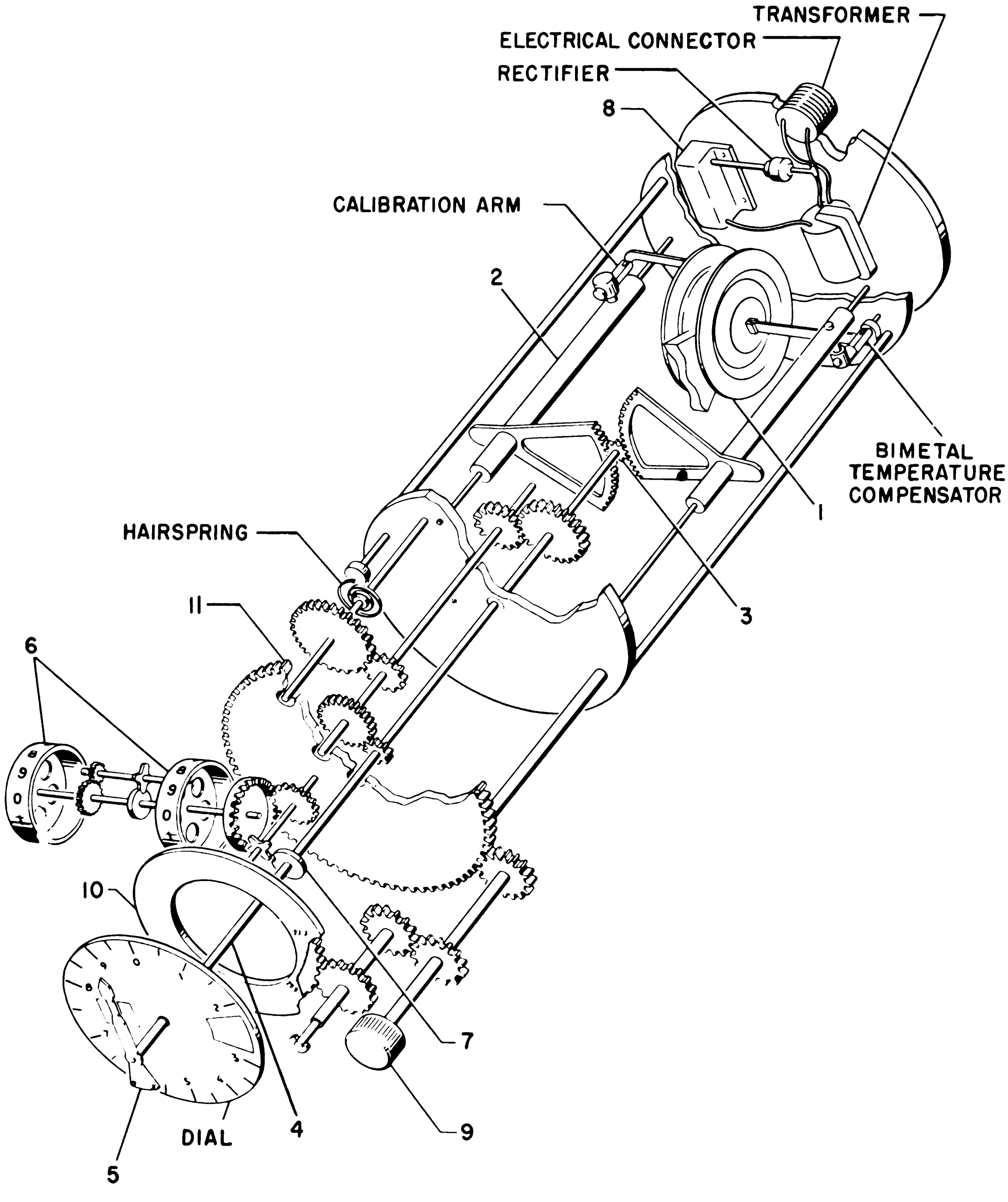
actuates the hand assembly (5) and drives the counter mechanism (6) by means of the disk (7). Because of the special design of the hand assembly (5), the counter indication is never obscured. An internal vibrator (8) is used to minimize friction during the instrument's operation.

Barometric corrections are made by turning the externally located knob (9) which engages the barometric dial (10) and the main plate assembly (11) which supports the entire mechanism. Adjustment is made with the knob so that the reading on the barometric dial will correspond to the actual barometric conditions of the area in which the aircraft is located or will be located upon landing.

Mechanical Errors

Altimeters are subject to various mechanical errors. A common one is that the scale is not correctly oriented to standard pressure conditions. Altimeters should be checked periodically for scale errors in altitude chambers where standard conditions exist.

Another type of error is due to the fact that the altimeter may tend to lag, particularly when large changes of altitude are made. These errors, which are called hysteresis or after effect, vary with the climb and descent. When an altimeter is taken aloft, to 19,000 feet for example, the indicated reading is slightly low, gradually increasing as time passes. This increase, called "drift," is due to the elastic properties which were loaded in a state of equilibrium by the heavier pressures of ground level and require time to reach a state of equilibrium under the lighter pressures at 19,000 feet. Likewise, if having remained at this altitude for several hours, the instrument will read slightly high upon descending and will gradually decrease, or recover, over a period of time.



1. Diaphragm assembly.
2. Rocking shaft assembly.
3. Main pinion assembly.
4. Handstaff assembly.
5. Hand assembly.
6. Counter mechanism.
7. Disk.
8. Internal vibrator.
9. Knob.
10. Barometric dial.
11. Main plate assembly.

Figure 19-23.—Mechanical schematic of a counter pointer pressure altimeter.

Improper installation or damage to the pitot-static tube or static parts will also result in improper indications of altitude.

RATE-OF-CLIMB INDICATORS

A rate-of-climb indicator indicates the rate at which an aircraft is climbing or descending. It is of primary importance for flying at night, through fog or clouds, or whenever the horizon is obscured. Another use is to determine if the maximum rate of climb is being secured during performance tests or in actual service.

The rate of altitude change, as shown on a climb indicator dial, is positive in a climb and negative in a dive or glide. The dial pointer, as shown in figure 19-24, moves in either direction from the zero point, depending on whether the aircraft is going up or down. In level flight the pointer remains at zero.

The Navy uses more than one type of climb indicator, the fundamental difference being their range. One type measures altitude changes up to 2,000 feet per minute; the others have a range up to 6,000 feet per minute.

Figure 19-25 illustrates the operation of a climb indicator. The case of the instrument is airtight except for a small connection through a restricted passage, or leak, to the static line from the pitot-static tube. In the indicator there are two chambers—one flexible (the capsule), and one inflexible (the instrument case). Both chambers receive air at atmospheric pressure from the static line. When the aircraft is on the ground or in level flight, the pressure in each chamber is the same; the air pressure on the inside and the outside of the diaphragm is equal and the pointer is at the zero indication.

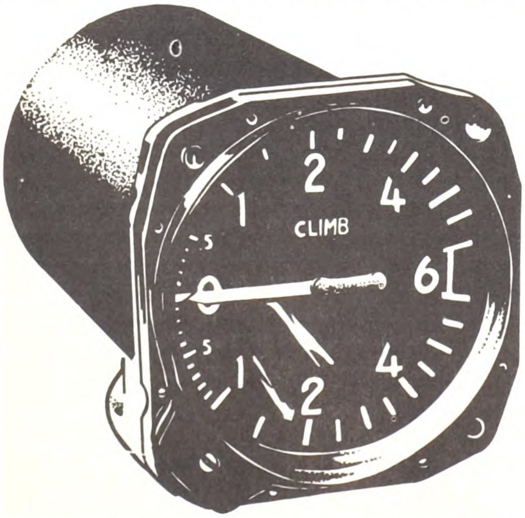


Figure 19-24.—Rate-of-climb indicator.

When air pressure is varying due to changing altitude, the pressure in the case lags behind the pressure in the diaphragm. The lag is caused by a restriction in the flow of air to and from the case. The resulting differential pressure actuates the mechanism producing a pointer deflection. The action that takes place during a climb is as follows. As the aircraft rises, the atmospheric pressure becomes lower and lower. The pressure in the capsule drops immediately because it is connected to the outside air by an unrestricted passage. The pressure in the instrument case starts to drop too, but cannot drop as fast as the pressure in the capsule because its outlet to the atmosphere is so tiny. Thus, the somewhat higher pressure in the instrument case tends to collapse the capsule—just as in an altimeter—and the mechanism connecting the capsule to the dial pointer indicates a climb.

When the aircraft levels off, the pressure in the instrument case equalizes the pressure in the capsule. The walls of the capsule return to a normal position and the pointer returns to zero.

In a dive, the pressure conditions are reversed. The capsule pressure immediately becomes greater than the pressure in the rest of the instrument case. Hence, the capsule expands and operates the pointer mechanisms to indicate the rate of descent.

The nature of a climb indicator is such that the indications lag behind the aircraft's actual climb or dive. When the aircraft departs from level flight, it may be several seconds before the pointer indicates the fact. Also, when it levels off after a climb or glide, the instrument may continue to indicate ascent or descent for as long as 12 seconds.

Errors and Corrections

Temperature changes have a tendency to cause variations in the flow of air through the small restricted leak passage of the instrument case. Various manufacturers of climb indicators compensate for this in different ways. All Navy instruments are equipped with temperature compensating features.

A leak in the instrument case of a climb indicator will produce incorrect readings by causing too rapid pressure changes in the case. The pointer will, therefore, indicate less than the actual rate of climb. Leaks must be located and corrected.

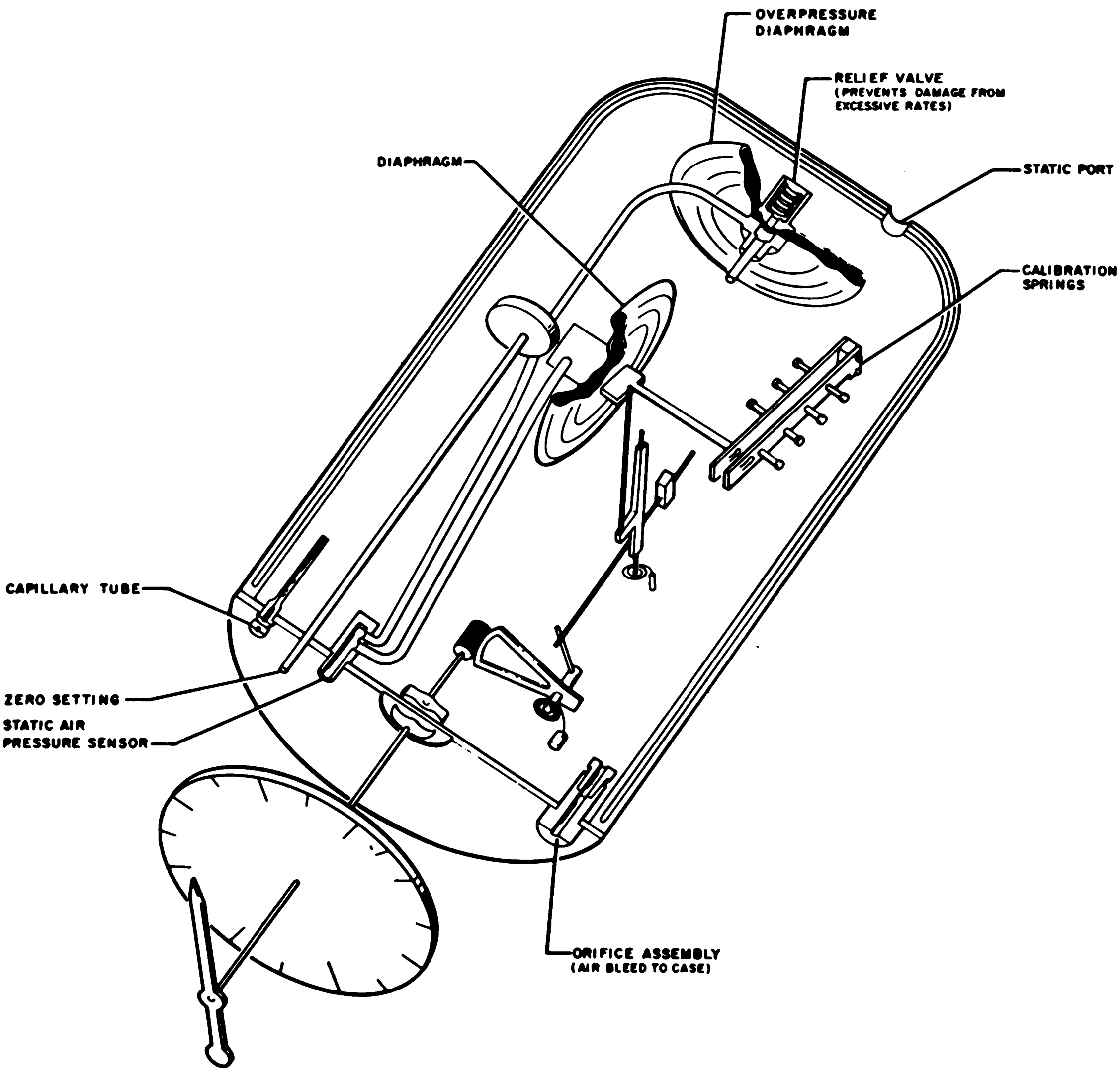


Figure 19-25.—Mechanical schematic of a rate-of-climb indicator.

A break in the leak passage (or "diffuser") assembly will have a similar effect on instrument operation, as such a break also allows instrument-case pressure to change too quickly. Do not attempt to repair a broken diffuser. Replace the broken assembly with a new one.

Climb indicators are equipped with a zero adjustment on the front of the case which can be used while the aircraft is on the ground to return the pointer to zero. Tap the instrument lightly to remove friction effects when making this adjustment.

ANGLE-OF-ATTACK INDICATORS

The angle-of-attack indicating system detects the local angle of attack of the aircraft from a point on the side of the fuselage and furnishes reference information for the control and actuation of other units and systems in the aircraft. Signals are provided to operate an angle-of-attack indicator (fig. 19-26 (A)), located on the pilot's instrument panel, where a continuous visual indication of the local angle of attack is displayed. A typical angle-of-attack

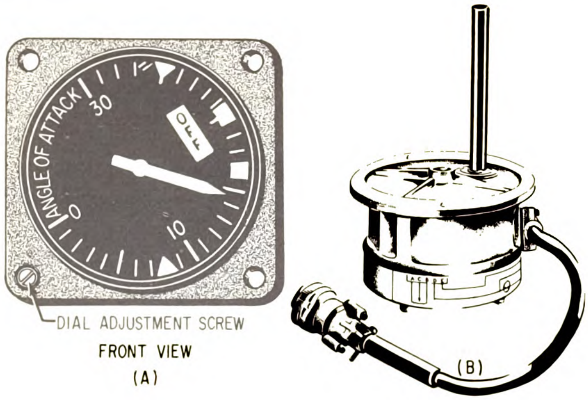


Figure 19-26.—Angle-of-attack indicator and transmitter.

system provides electrical signals for the operation of a rudder pedal shaker which warns the pilot of an impending stall when the aircraft is approaching the critical stall angle of attack. Electrical switches are actuated at the angle-of-attack indicator at various preset angles of attack that energize colored lights in the approach light system and an approach index light in the cockpit. These lights, completely automatic, furnish the Landing Safety Officer and the pilot with an accurate indication of approach angle of attack during landing. An angle-of-sideslip system (consisting of an airstream direction detector and an angle-of-attack and angle-of-slideslip compensator) is installed on some aircraft. The outputs from these are used for controlled rocket firing.

The angle-of-attack indicating system consists of an airstream direction detector (transmitter) (fig. 19-26 (B)), and an indicator located on the instrument panel. The airstream direction detector contains the sensing element which measures local airflow direction relative to the true angle of attack by determining the angular difference between local airflow and the fuselage reference plane. The sensing element operates in conjunction with a servo-driven balanced bridge circuit which converts probe positions into electrical signals.

The operation of the angle-of-attack indicating system is based on detection of differential pressure at a point where the airstream is flowing in a direction that is not parallel to the true angle of attack of the aircraft. This differential pressure is caused by changes in airflow around the probe unit. The probe extends through the skin of the aircraft into the airstream.

The exposed end of the probe contains two parallel slots which detect the differential airflow pressure (fig. 19-27). Air from the slots is transmitted through two separate air passages to separate compartments in a paddle chamber. Any differential pressure, caused by misalinement of the probe with respect to the direction of airflow, will cause the paddles to rotate. The moving paddles will rotate the probe, through mechanical linkage, until the pressure differential is zero. This occurs when the slots are symmetrical with the airstream direction.

Two electrically separate potentiometer wipers, rotating with the probe, provide signals for remote indications. Probe position, or rotation, is converted into an electrical signal by one of the potentiometers which is the transmitter component of a self-balancing bridge circuit. When the angle of attack of the aircraft is changed and, subsequently, the position of the transmitter potentiometer is altered an error voltage exists between the transmitter potentiometer and the receiver potentiometer in the indicator. Current flows through a sensitive polarized relay to rotate a servomotor located in the indicator. The servomotor drives a receiver potentiometer in the direction required to reduce the voltage and restore the circuit to a null or electrically balanced condition. The polarity of the error voltage determines the resultant direction of rotation of the servomotor. The indicating pointer is attached to, and moves with, the receiver potentiometer wiper arm to indicate on the dial the relative angle of attack.

The adjustable cams (switches) which control the approach light, approach indexer, and stall warning are shown in figure 19-28.

The cams are actuated as the indicator responds and the relationship of the indicator to

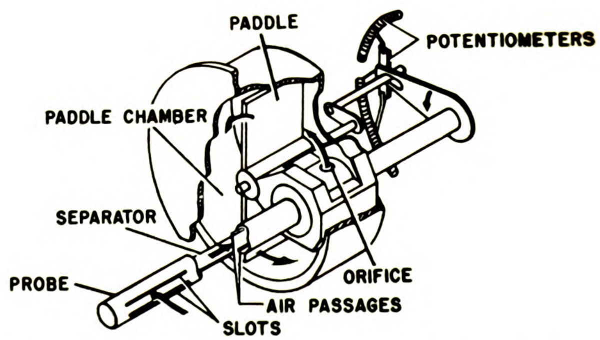


Figure 19-27.—Mechanical schematic of an airstream direction detector.

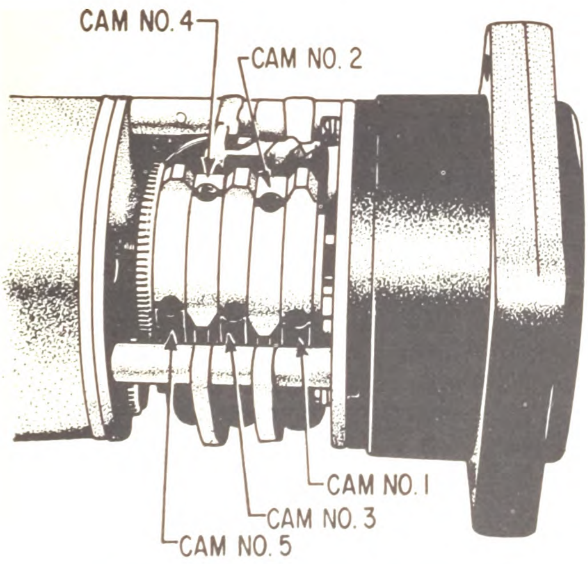


Figure 19-28.—Angle-of-attack indicator cams.

the lights and stall warning is shown in figure 19-29.

When making adjustments on the cams of the indicator, follow the instructions outlined in the Maintenance Instructions Manual for the squadron's aircraft.

AIR DATA COMPUTERS

A recent addition to the Navy's aircraft navigational equipment is the air data computer system. The most significant difference between this equipment and older navigational aids is that it operates entirely on information derived within the aircraft itself. The Central Air Data Computer (CADC) system, used in the F-4B aircraft, is an electromechanical-pneumatic computer which provides various systems in the aircraft with corrected static pressure, Mach number, true airspeed, angle of attack, and altitude and gain changing data. A data flow diagram of the CADC system is shown in figure 19-30.

The principal part of the system, the computer unit, receives temperature, angle of attack, pitot and static pressures, engine bleed air pressure data, and develops true corrected outputs through the computing elements. The CADC provides direct reading indications of true airspeed and angle of attack. Failure of the static pressure compensator prevents the computer from providing corrected static pressure outputs; and a failsafe, bypass valve is automatically actuated, allowing uncorrected static pressure to be used. When the fail-safe, bypass valve is actuated, a warning light on the outboard engine control panel will inform the pilot that instrument readings may be in error due to lack of static pressure correction.

The CADC is completely automatic while the engines are operating. A reset static correction switch is located on the pilot's outboard engine control panel near the warning light. When pressed, the switch breaks the circuit to the warning light and resets the compensator. When the switch is released, the warning light will continue to glow if the compensator has not reset.

For more detailed information on the CADC, the AE should consult the Maintenance Instructions Manual or Aviation Electrician's Mate 1 & C, NavPers 10349-A.

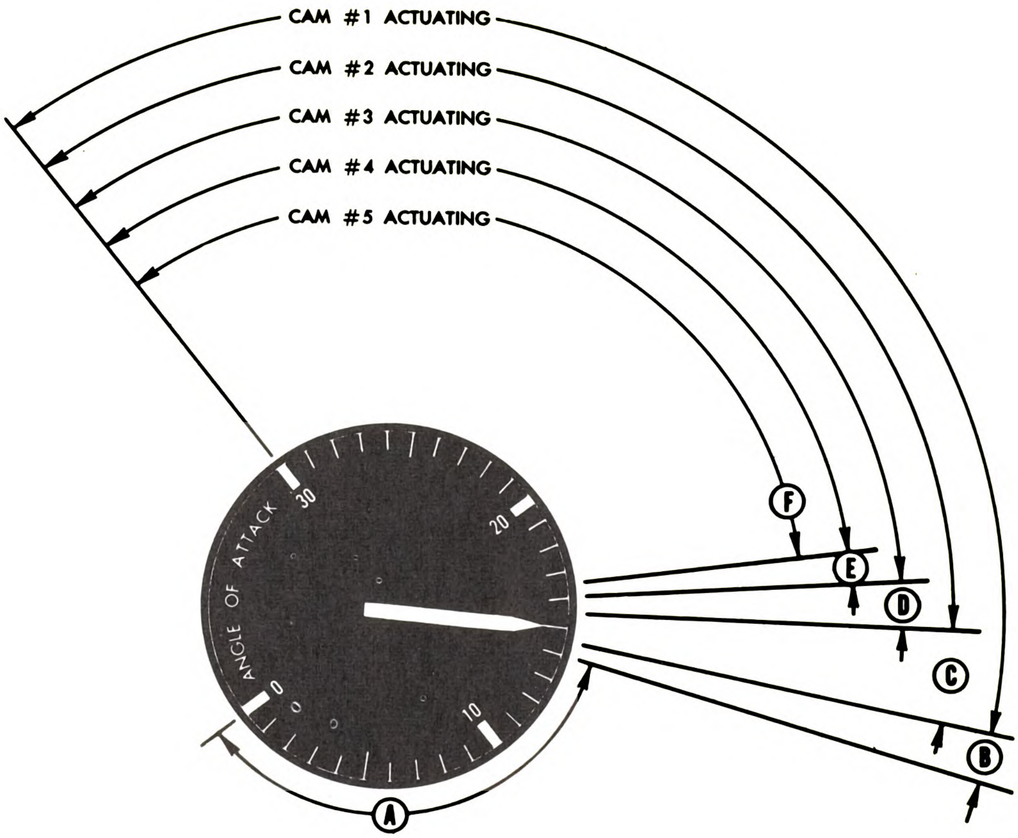
SHIPPING AND HANDLING

Instruments in need of repair should be handled with the same care that is exercised in handling new instruments, in order that additional damage due to improper handling may be avoided. In order to prevent damage in handling and storage, all instruments insofar as practicable are stored and transported in individual cartons. Care should be taken in packing damaged instruments to insure that no additional damage will result during shipment. Individual cartons are packed for shipment in strong wooden boxes, except where the means of shipment, such as by air, prohibits such packing.

Instruments requiring caging, such as Flux Gate compass transmitters, directional gyros, and gyro horizon indicators, should be placed in the caged position prior to shipment. Refer to the manufacturer's instructions for detailed information regarding the caging of a particular instrument.

CLEANING

All aircraft instruments, after being removed from the aircraft and before shipping to supply, should be cleaned externally. If such instruments are fluid transmitters or pressure indicators, such as fuel flow transmitters and Bourdon type instruments, they should be drained



RELATIONSHIP CHART

CODE	INDICATOR UNITS	ACTUATING CAMS	APPROACH LIGHT	APPROACH INDEXER	STALL WARNING
A	0 — 14	NONE	RED	/ \	NONE
B	14 — 14.5	1	AMBER	= / \	NONE
C	14.5 — 15.5	1-2	AMBER	=	NONE
D	15.5 — 16	1-2-3	AMBER	\ / =	NONE
E	16 — 16.5	1-2-3-4	GREEN	\ /	NONE
F	16.5 — 30	1-2-3-4-5	GREEN	\ /	CONTROL PEDAL SHAKER

Figure 19-29.—Angle-of-attack relationship chart.

to insure that no fluid remains inside the instrument.

Extreme care should be exercised to prevent contamination of instruments with perspiration. Thoroughly dry the instruments before wrapping with moistureproof material.

CONTAINERS

All instruments and accessories when received from supply will be in containers. Two types are used, nonmetallic and metallic.

Figure 19-31 shows a cutaway view of a typical nonmetallic type package. These containers

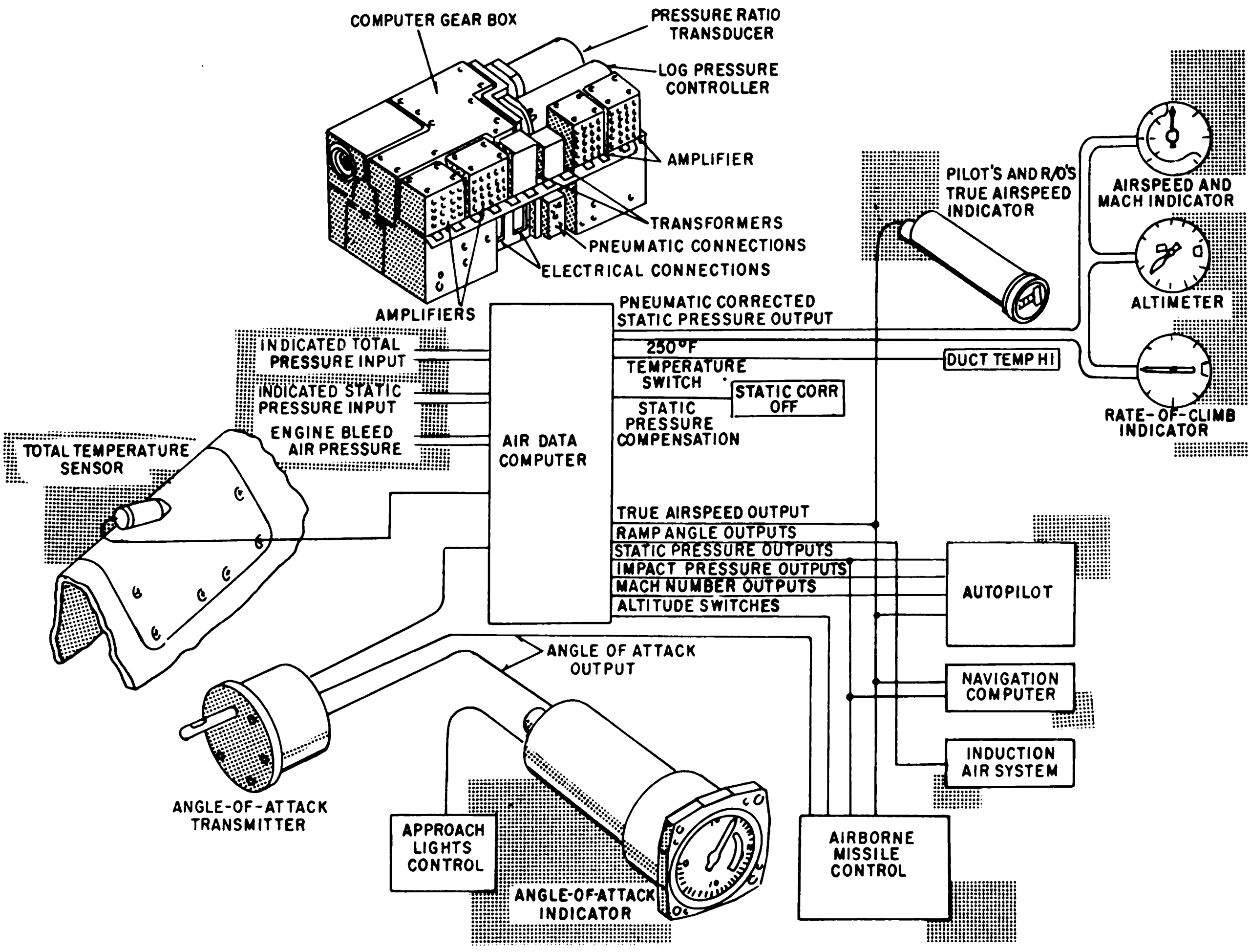


Figure 19-30.—Flow diagram of CADC system.

are usually constructed of a high-grade cardboard. They will not withstand the rough treatment that the metallic type container can endure; however, if they are not abused, they afford adequate protection for the instruments.

Figure 19-32 shows a cutaway view of a typical metallic type package. These containers are of two general types. One is a light gage can similar to the common tin can used in preserving food. The other is constructed of a heavier gage metal and is equipped with a lid that is secured to the can with a snapring fastener. This type can may be opened and closed without any damage to the container.

Even though the light metal can must be opened by cutting the top out with a can opener, it is still reusable for shipping some instruments to supply. The most common means of resealing a can of this type is by securing the lid in position with masking tape.

Both the nonmetallic and metallic containers and the packing material therein should not be damaged or thrown away after the instrument has been removed. Provision should be made for keeping them in the electric shop since they may be used for returning equipment to supply. Many of them are labeled "REUSABLE CONTAINER—DO NOT DESTROY."

WRAPPING AND CUSHIONING

Instruments must be wrapped in a barrier material, such as aluminum foil, for protection from moisture. The amount of wrapping should be such that the instrument is enclosed within at least two thicknesses of the barrier material.

The wrapping should be held securely in place, preferably by tape.

When packaging instruments, a cushioning material must be used. Two of the best materials are dry cellulose-crepe wadding and hair-latex dunnage. All cushioning materials must meet federal specifications. When cushioning an instrument, be sure that the material is dry; also, be sure that it is of sufficient thickness to protect the instrument.

Pack the container firmly to prevent motion of the instrument which may result in damage during transit. In most cases the wrapping and cushioning materials are reissued along with the container.

Refer to figures 19-31 and 19-32 to determine how the materials just described are used when packing instruments.

LABELING

After the instruments have been cleaned, wrapped, cushioned, and packaged, it is necessary to make sure that the correct labeling is placed on the outside of the container.

The label should include the component name, part number, stock number, and the squadron or activity sending the container. When possible, the instrument being returned should be replaced in its original container. This container will already be marked with all or almost all of the necessary identifying data.

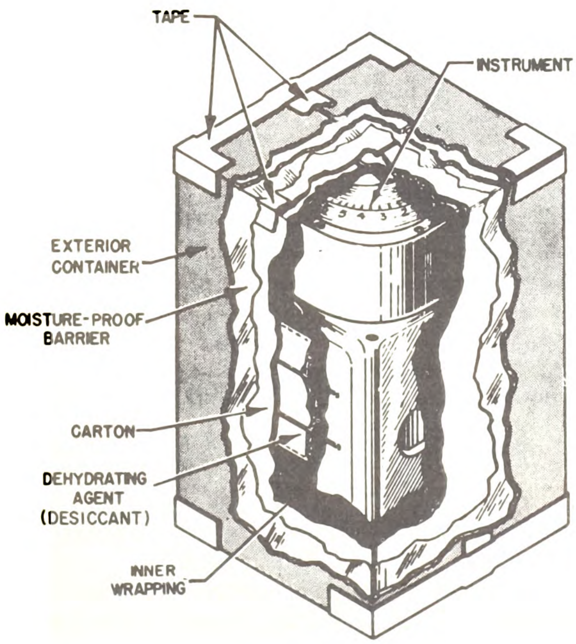


Figure 19-31.—Nonmetallic packing—numbered in sequence.

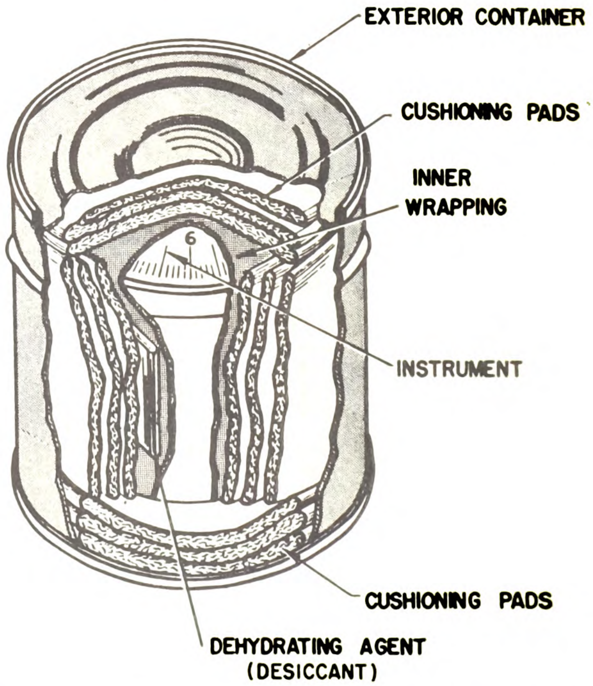


Figure 19-32.—Metallic packaging—numbered in sequence.

CHAPTER 20

AIRCRAFT INSTRUMENT SYSTEMS—CONTINUED

REMOTE INDICATING INSTRUMENTS

SYNCHRO TYPE

A synchro system is an electrical system used for transmitting position information from one point to another. An example of a typical synchro system is a remote oil pressure indicating system. In this type installation an oil pressure transmitter is installed at some point in the aircraft remote from the cockpit. The only connections between the transmitter and the indicator, which is located in the cockpit, are the interconnecting wires.

There are different types of synchro systems. The four most common are the Autosyn, Selsyn, Magnesyn, and Microsyn. (These are trade names.) These systems are practically identical in construction and all operate on electrical and mechanical principles that are very similar. The AE who understands the purpose and principle of operation of one of the systems, should experience little difficulty in applying the knowledge to any of the other systems.

A simple synchro system is shown in figure 20-1. This system consists of a synchro receiver and a synchro transmitter, with the interconnecting wires.

Synchro systems are used to measure angular displacements. These angular displacements are normally derived from the movement of some mechanical part, such as a wing flap or a landing gear, or from a change in pressure of or the movement of some liquid or gaseous matter.

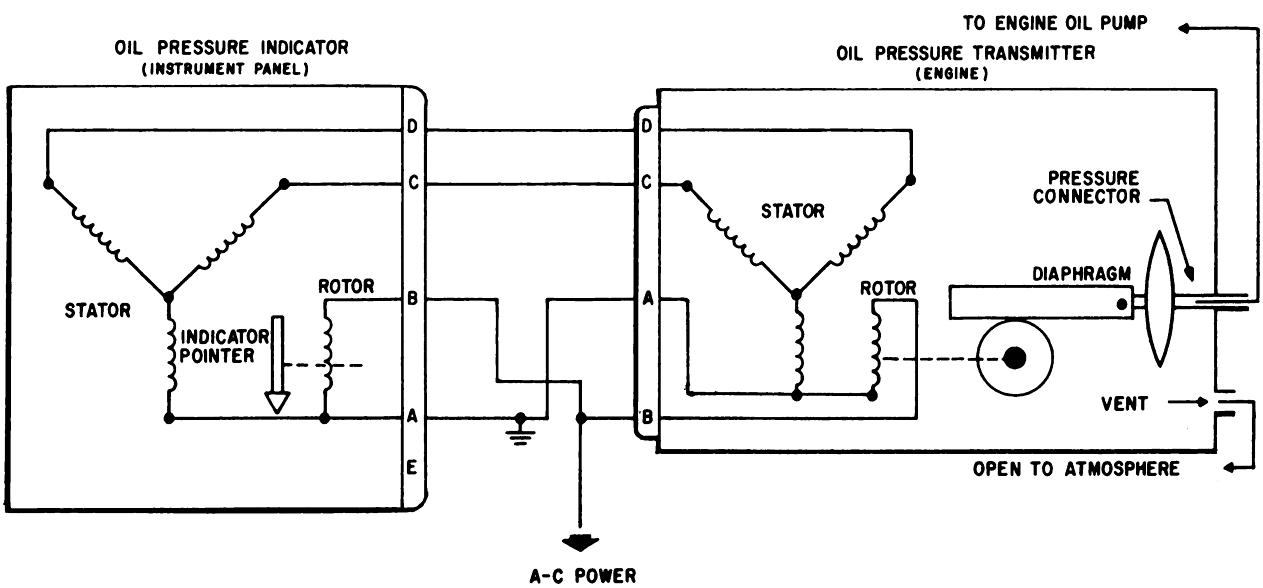


Figure 20-1.—Oil pressure synchro system.

Fuel and Oil Pressure

Fuel pressure and oil pressure indications are conveniently obtained by means of synchro systems. The type of system used is the same for both fluids. (However, the oil system transmitter is not interchangeable with the fuel system transmitter.)

The synchro system shown in figure 20-1 is for indicating oil pressure. A change in oil pressure introduced into the synchro transmitter causes an electrical signal to be transmitted through the interconnecting wiring to the synchro receiver. This signal causes the receiver rotor and the indicator pointer to move a distance proportional to the amount of pressure exerted by the oil.

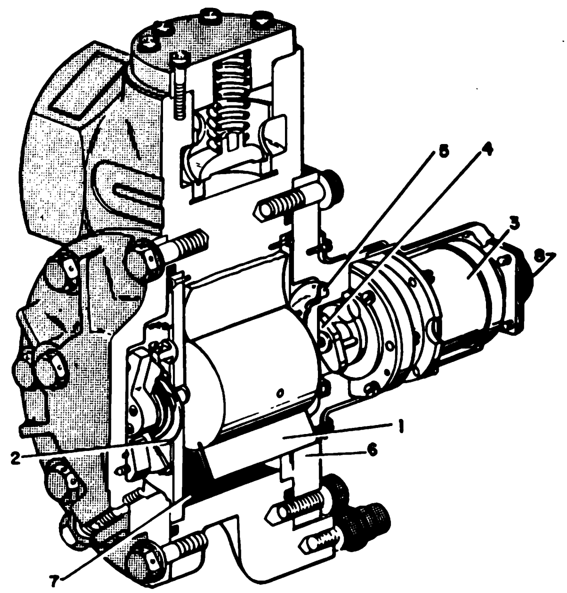
Fuel Flowmeters

AUTOSYN FUEL FLOWMETERS.—The fuel flow indicating system provides a continuous indication of the rate that fuel is being delivered to the engine in pounds per hours. The indicator of some systems also indicates the amount of fuel remaining in the tanks. A typical Autosyn flowmeter consists of two units—a transmitter and an indicator. The measurements are transmitted electrically to the panel-mounted indicator. The use of electrical transmission eliminates the need for a direct fuel-filled line from the engine to the instrument panel. Possibilities of fire hazard and mechanical failures are greatly minimized.

The Autosyn fuel flowmeter system is quite similar to other synchro systems discussed in Basic Electricity, NavPers 10086-A. NOTE: The discussion that follows is based on an understanding of the operation of the basic Autosyn system. A typical fuel flow indicating system is described in order to acquaint the AE with flowmeters in general. However, the AE should always refer to the manuals for the particular type system that he is maintaining.

Figure 20-2 shows the cutaway view of a fuel flow transmitter. It is a two-in-one unit, being made up of a fuel-measuring mechanism (or meter) and an Autosyn transmitter. These parts can be separated from one another for maintenance purposes, but are joined together as a single assembly for installation.

The fuel enters the inlet port of the transmitter and is directed against the vane (1), (fig. 20-2), causing the vane to swing. The spiral fuel chamber is so designed that the



1. Vane.
2. Hairspring.
3. Autosyn transmitter.
4. Bar magnet assembly.
5. Ring magnet assembly.
6. Transmitter mounting frame.
7. Fuel chamber.
8. Electrical connector.

Figure 20-2.—Cutaway view of fuel flow transmitter.

distance between the vane and the chamber wall becomes increasingly larger as the rate of flow increases. A calibrated hairspring (2) retards the motion of the vane. When the force exerted by the hairspring on the vane is equal to the force exerted by the fuel on the vane, motion of the vane will cease.

The rotor shaft of the Autosyn transmitter (3) is linked to a bar magnet (4). Attached to the vane shaft is a ring magnet (5); the ring magnet moves as the vane shaft moves. The transmitter mounting frame is located between the bar magnet and the ring magnet, forming a liquid-tight seal between the fuel-metering section of the mechanism and the Autosyn. However, the bar magnet will move in unison with the ring magnet since the two magnets are magnetically coupled, the south pole of the ring magnet being opposite the north pole of the bar magnet. Movement of the vane, caused by the flow of fuel, is transmitted by the two magnets to the Autosyn rotor, resulting in a corresponding movement of the rotor. Therefore, the

relative position of the Autosyn rotor, with respect to the Autosyn stator, is determined by the angular displacement of the vane in relation to the housing of the fuel chamber.

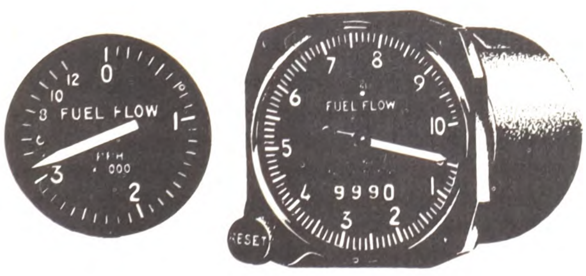
The fuel flow transmitter is equipped with a relief valve which automatically opens and bypasses the instrument whenever the fuel flow exceeds the capacity of the instrument—as it may during takeoff, for example. At such time, only part of the fuel flows through the metering portion. As soon as the pressure across the instrument falls below the value at which the relief valve is set, the valve closes and the flowmeter again operates normally. The transmitter unit is located in the fuel line between the fuel pump and the carburetor or fuel nozzle.

The fuel flowmeter indicator, located on the instrument panel, is a remote indicating Autosyn instrument. It consists of an Autosyn receiver, a step-up gear train, a magnetic drag cup, and a calibrated spring. When fuel flows through the fuel flow transmitter, an electrical signal is sent to the indicator receiver. This causes the Autosyn rotor to assume a position in accordance with the signal that is coming from the transmitter. Thus, the indicator pointer indicates the rate of fuel flow by positioning itself on the dial.

Figure 20-3 (A) shows the face of an Autosyn fuel flow indicator. To determine the amount of fuel being consumed per hour, multiply the scale reading by 1,000. A schematic diagram of the single Autosyn fuel flow indicator system is shown in figure 20-4.

Fuel Flow Totalizing Systems

Figure 20-3 (B) shows the indicator of a fuel flow totalizing system. The pointer of this



(A) (B)

Figure 20-3.—(A) Fuel flow indicator; (B) fuel flow totalizing indicator.

instrument usually indicates the combined rate of fuel flow into two or more engines. However, it will also give a true indication if only one engine is being operated. In the small window appears a continuous reading of how many pounds of fuel remain in the aircraft fuel cells. The fuel cells, when full, contain a certain number of pounds of fuel. The fuel quantity indicator will indicate how many pounds. Before starting the engines, this total amount of fuel in the aircraft is set on the pounds fuel remaining indicator. This is done with the reset knob on the front of the instrument. As soon as the engines are started and begin consuming fuel, the fuel flow pointer indicates how fast the fuel is being used. The pounds fuel remaining indicator starts counting backward toward zero, thus giving a continuous reading of how many pounds of fuel remain in the cells. Numbers rotate past the window in a manner quite similar to that of the mileage indicator of an automobile speedometer.

The entire fuel flow totalizing system consists of two or more fuel flow transmitters, an amplifier, and an indicator.

The fuel flow transmitters are almost identical to those already discussed in the Autosyn single system. In the fuel flow totalizing system, the transmitters are connected electrically so that their combined signals are fed as one into the fuel flow amplifier.

The fuel flow amplifier is an electronic device which supplies power of the proper magnitude and phasing to drive the indicator. The speeds at which the indicator motor is driven depends on the transmitter signal fed into the amplifier.

The fuel flow totalizer indicator contains a 2-phase variable speed induction motor. This motor is always driven in one direction only, but at varying speeds. As the rate of fuel consumption by the engines increases, more and more power is fed to the indicator motor. This causes the speed of the motor to be proportional to the rate of fuel consumption. The motor turns a magnetic drum-and-cup linkage (similar to the hysteresis cup in the tachometer indicator) which causes a pointer deflection proportional to the motor speed and thus proportional also to the rate of fuel consumption At the same time, another linkage employing a friction clutch drives the pounds fuel remaining indicator. This clutch is disengaged by the reset knob when the knob is used to set a reading on the pounds fuel remaining indicator.

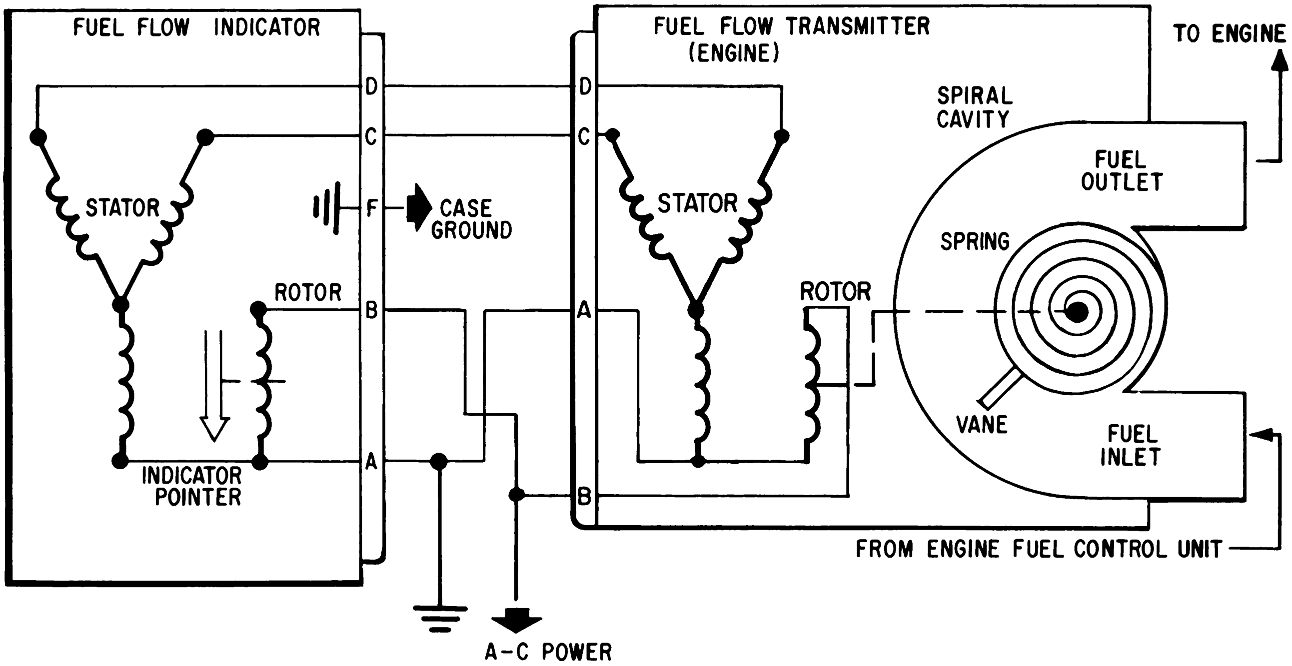


Figure 20-4.—Single fuel flow indicating system.

VERTICAL SCALE INDICATORS

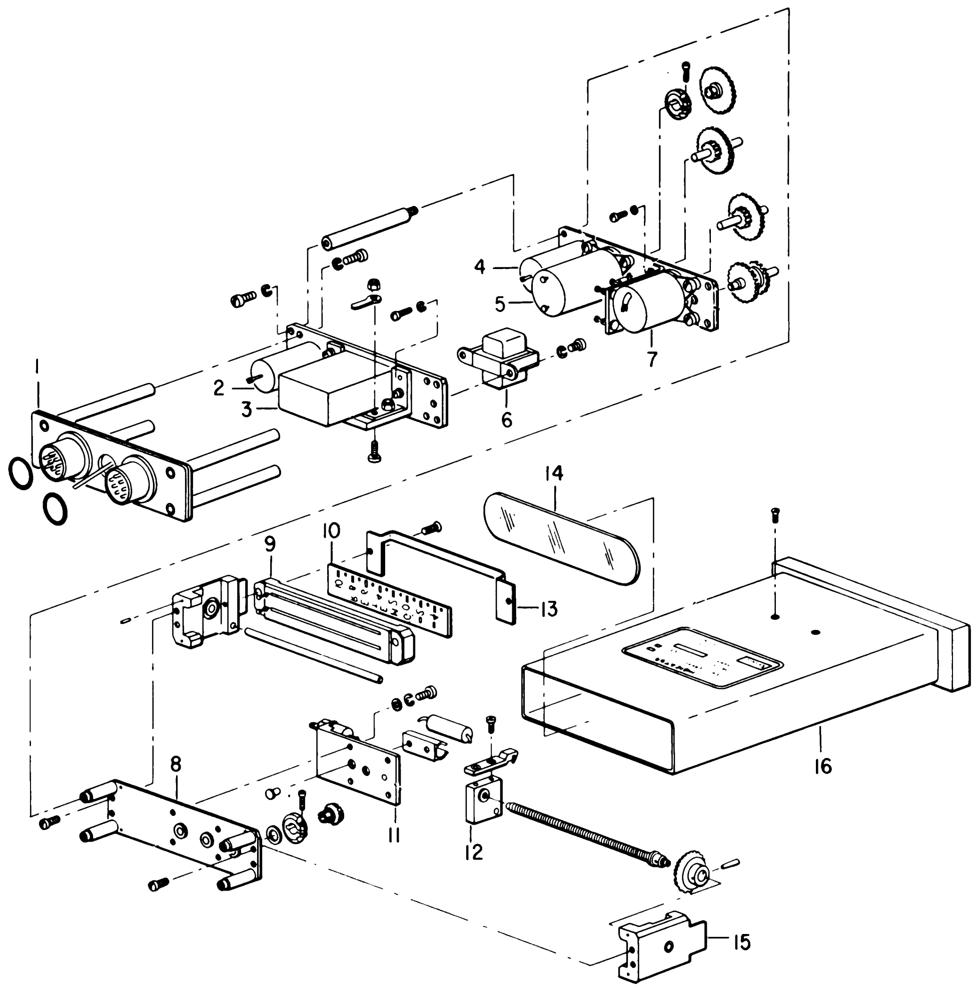
On some modern naval aircraft, such as the A-6A, a new concept of instrumentation is employed. In preference to radial dial indicators, the vertical scale indicator is used to indicate engine performance data such as fuel flow, engine speed, and exhaust gas temperature and accelerometer readings. Vertical scale indicators are compact, light in weight, and very easily read.

Basically all vertical scale indicators consist of a vertical thermometer type tape that is actuated by an amplifier, motor, gears, and sprockets. (See fig. 20-5.)

Vertical Scale Fuel Flow Indicator

The dual flow indicator (fig. 20-6) consists of two independent channels, assembled in one module, that provide rate-of-fuel flow indications for each engine. Each channel of the dual indicator consists of a vertical thermometer-type tape that is actuated by an amplifier, motor, gears, and sprockets. The tape runs parallel along a scale to a point indicating the engine rate-of-fuel flow. The channels and tapes are marked L FF (left fuel flow) and R FF (right fuel flow). The face of the dual indicator has a scale range from 300 to 10,000 pounds per hour (pph), with linear markings in units of 100 pph from 300 to 5,000 pph and units of 1,000 pph from 5,000 to 10,000 pph. Numerical markings are 1, 2, 3, 4, 5, and 10 (multiplied by 1,000) indicating pounds per hour. All markings are white on a translucent dull black background. Flags located on the sides of the dual indicator will drop, exposing the word OFF, if power fails or is not applied to either channel of the indicator.

The dual indicator electromechanical components, and the receptacle located on the backplate, are assembled in one module and hermetically sealed in a glass-faced metal case. The receptacle mates with a plug connected to



1. Connector plate.
2. Capacitor fixed.
3. Amplifier servo.
4. Capacitor fixed.
5. Potentiometer 2K.
6. Power transformer.
7. Servomotor.
8. Gear plate.
9. Lamp assembly.
10. Dial.
11. Gear support.
12. Carriage.
13. Dial mask.
14. Window.
15. Support.
16. Bezel and cover assembly.

Figure 20-5.—Exploded view of a vertical scale indicator.

wiring from the left engine fuel flowmeter transmitter, the right engine fuel flowmeter transmitter, the electrical power supply for the fuel-flow indicator power supplies and the electrical supply for the indicator lighting. When the indicator internal lighting is one, all white markings and the vertical tape will show red on the translucent black background. Mounting holes are located on the front of the metal case.

Each channel of the flow indicator operates in conjunction with a flow transmitter. (See fig. 20-7.) This transmitter converts fuel flow rate in pounds per hour into a corresponding

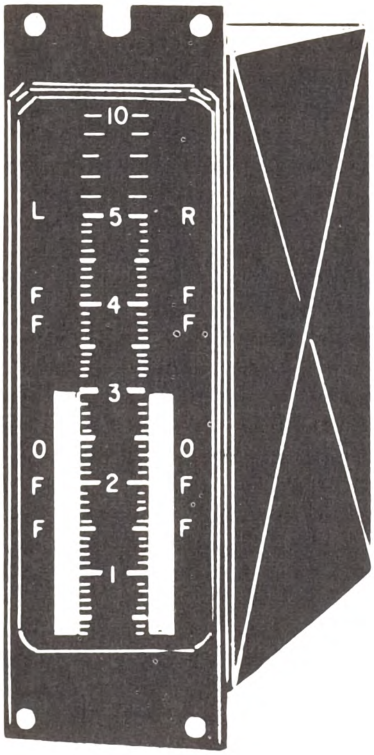


Figure 20-6.—Vertical scale dual fuel flow indicator.

shaft position which is converted into an electrical signal by a synchro transmitter. The fuel flow indicator converts the electrical signal back to a shaft position via a servo-driven synchro control transformer. Since the field of the control transformer is connected to the field of the transmitter, output from the control transformer rotor is zero when this rotor is at a right angle to the transmitter rotor. At other rotor positions, the output is proportional to the deviation of the two rotors from a right angle alinement. This output, indicating the degree of misalinement between the rotors, is the error signal.

By amplifying the error signal to operate a servomotor, and gearing the servomotor to the shaft of the control transformer, the system becomes self-correcting; any error signal at the control transformer rotor rotates the servomotor to cancel itself. The servosystem, therefore, causes the control transformer to follow, with fixed 90° angular displacement, the synchro transmitter in the flow rate transmitter. The angular position of the synchro transmitter is proportional to the fuel flow measured; therefore, control transformer rotor position is proportional to flow rate. The tape drive sprocket, geared to the control transformer, displays this rate of fuel flow.

An independent sensing and indicating channel is provided for each engine. Electrical signals from the synchro transmitter, located in the fuel flowmeter transmitter, are converted into a shaft position by means of a control transformer in the fuel flow indicator (fig. 20-8).

System accuracy is provided by an amplifier that furnishes power gain between the control transformer and the motor. A feedback signal is connected in series with the control transformer output signal to insure stable operation of the servosystem.

The error signal is amplified to a sufficiently high power level to operate a servomotor. Gearing this servomotor mechanically to the rotor shaft of the control transformer makes this system self-correcting. If an error signal exists at the control transformer rotor, the servomotor rotates the control transformer rotor in the proper direction to cancel itself. The motor also operates a gear train that positions the moving tape indicator. A gear train also operates a digital encoder which provides a digital equivalent of fuel flow rate. The gear train consists of a motor with a geared shaft, four reduction gear assemblies, a geared sprocket assembly, a gear on the synchro control transformer, an idler gear, and the encoder gear. Signals from the fuel flowmeter transmitter are fed to the synchro control transformer, converted, and passed through the amplifier portion to actuate the motor. The geared motor shaft drives a 41.25 to 1 gear train, consisting of the first- and second-reduction gear assemblies, which in turn drives the geared sprocket assembly through one gear of the third-reduction gear assembly used as an idler gear to position the vertical tape. A 6.8571428 to 1 gear train, consisting of an idler gear, driven by the second, third, and fourth reduction gear assemblies, positions the gear on the synchro control transformer. When the rotor in the synchro control transformer is at a right angle to the rotor of the synchro transmitter (fuel flowmeter transmitter) control transformer output is zero. A 1 to 2.4 gear train consisting of an idler gear assembly, driven by the synchro control transformer gear, positions the encoder gear.

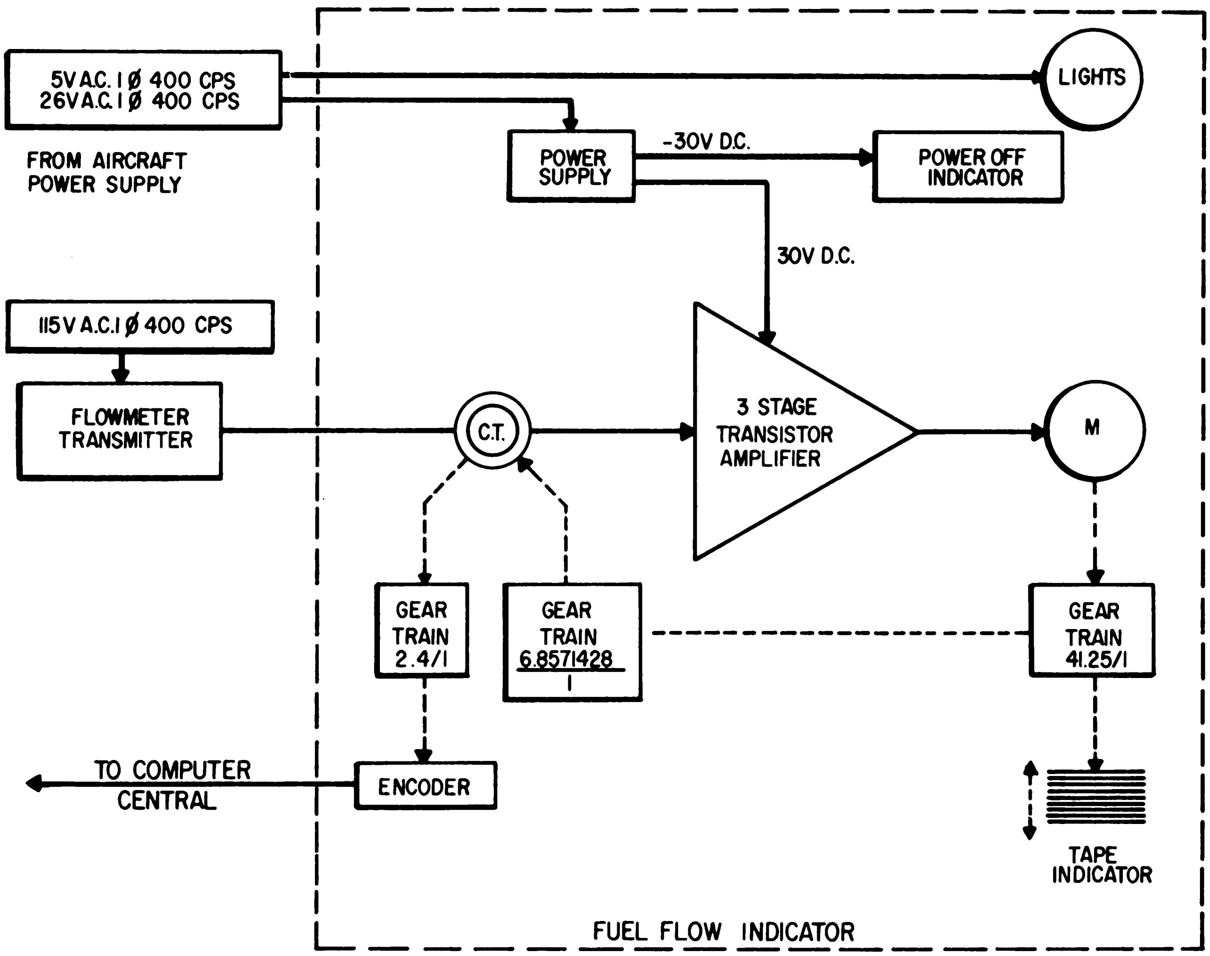


Figure 20-7.—Block diagram of fuel flow indicating system.

POSITION INDICATING INSTRUMENTS

D-c Selsyn Systems

A d-c Selsyn system is an electrical method of indicating a remote mechanical condition. Specifically, d-c Selsyn systems are used to show the movement and position of retractable landing gear, wing floats, wing flaps, cowl flaps, oil cooler doors, or similar movable parts of the aircraft.

A d-c Selsyn system consists of a transmitter, an indicator, and connecting wires. A d-c voltage from the aircraft's electrical power system supplies the required voltage to operate the system. The transmitter part of the system is connected through a mechanical system called a linkage to the movable mechanical parts that are actually doing the measuring. The indicator repeats this information on a properly calibrated scale in the indicator on the instrument panel.

THREE-WIRE SYSTEM.—A complete three-wire system is illustrated in figure 20-9. The transmitter consists of a circular resistance winding and a rotatable contact arm. The rotatable contact arm turns on a shaft in the center of the resistance winding. The two ends of the arm, or brushes, always touch the winding on opposite sides. Thus, the arm can be turned so that voltage can be applied at any two points around the circumference of the winding. The shaft to which the arm is fastened sticks out through the end of the transmitter housing and is attached to

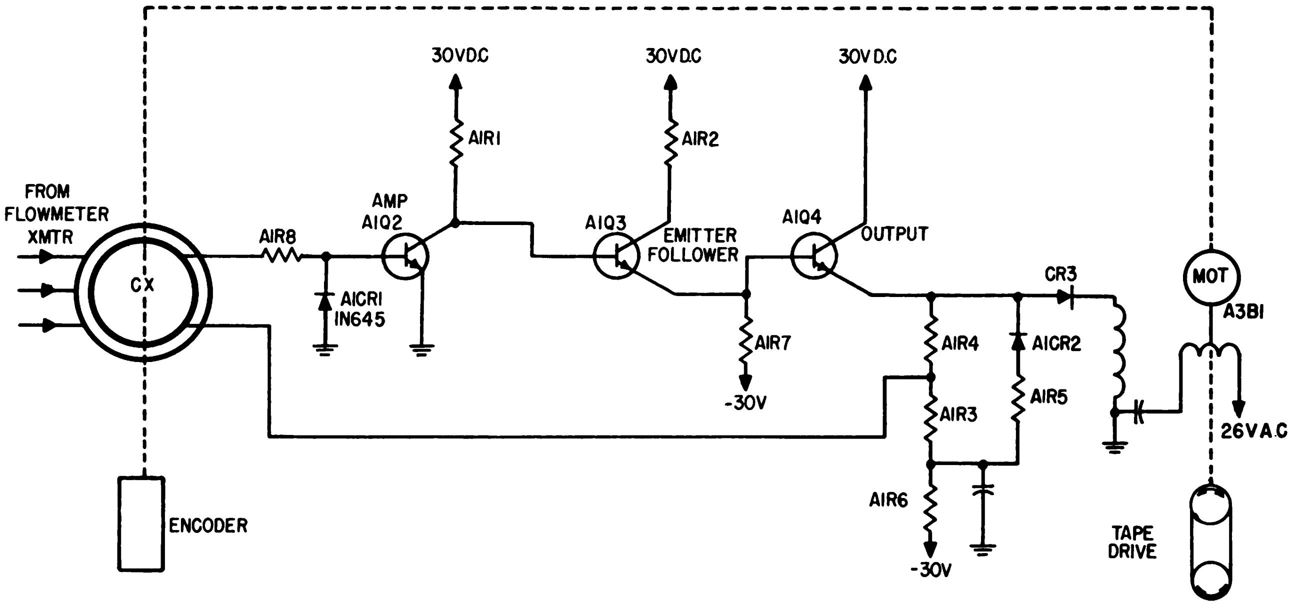


Figure 20-8.—Simplified schematic of a vertical scale fuel flow indicator.

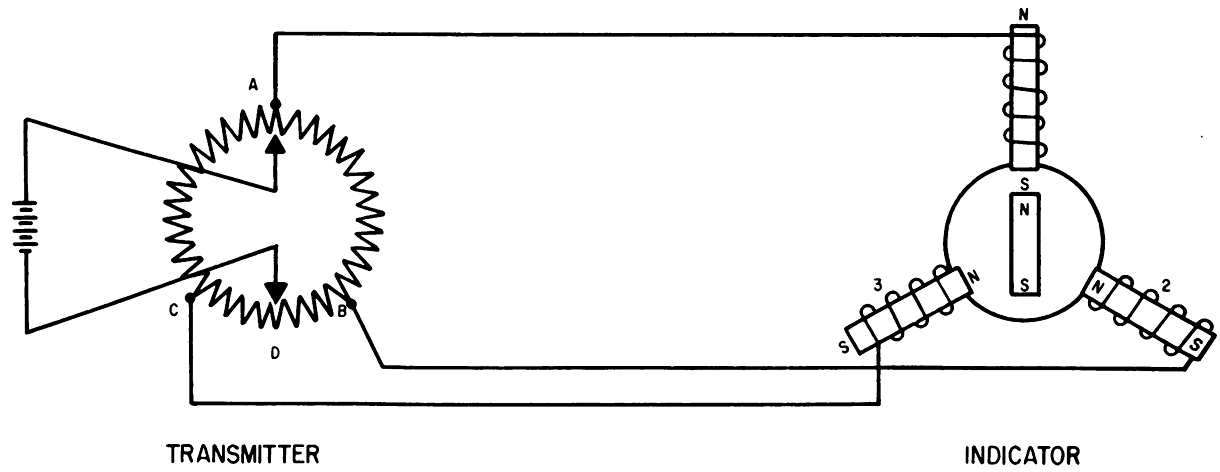


Figure 20-9.—Three-wire Selsyn system.

the mechanical device that is doing the actual measuring. As this mechanical device moves, it causes the transmitter shaft to turn.

As the voltages at the transmitter taps are varied, the distribution of currents in the indicator coils varies and the direction of the resultant magnetic field across the indicator is changed. Actually, the magnetic field across the indicating element corresponds in position to the moving arm in the transmitter. Whenever the magnetic field changes direction, the polarized motor turns and alines itself with the new position of the field. The rotor, therefore, indicates the position of the transmitter arm.

When the d-c Selsyn system is used to indicate the position of landing gear, an additional circuit is connected to the transmitter winding, called a lock switch circuit. The purpose of this circuit is to show when the

landing gear is up and locked, or down and locked. Lock switches are shown connected into the three-wire system in figure 20-10.

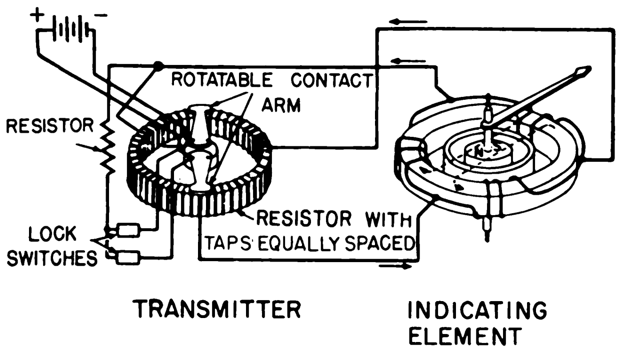


Figure 20-10.—Three-wire Selsyn with double-lock switch.

The added resistor is connected between one of the taps of the transmitter at one end and to either the positive or negative voltage supply at the other end, depending on the position of the individual lock switches. When either lock switch is closed, the resistance is added into the transmitter circuit to cause an unbalance in one section of the transmitter winding. This unbalance causes the current flowing through one of the indicator coils to change. The resultant movement in the indicator pointer shows that the lock switch has been closed. The lock switch is mechanically fastened in the wheel wells so that when the landing gear locks either up or down, it closes the lock switch connected to the Selsyn transmitter. This locking of the landing gear is therefore repeated in the indicator on the instrument panel so that the pilot knows when the landing gear is locked up or down.

Wheels and Flaps Position Indicating System

An example of a position indicating instrument is a wheels and flaps position indicating system used in a current aircraft. This indicating system (fig. 20-11) consists of two subsystems, the wheels position and the flaps position. Both systems are incorporated within one indicator. The indicator is located on the instrument panel. Its function is to provide the copilot with a definite indication of whether the landing gear is fully locked up or locked down, and the exact position of the flaps.

The indicator is made up of four polarized solenoid elements. Three of these elements are identical and consist of a two-section coil through which a magnetized drum dial rotates. When the wheels are locked up, power from the d-c bus is supplied through the uplock limit switches (located on the landing gear) to the up side of the coils, magnetizing the dials to indicate UP on the indicator. When the wheels are locked down, d-c power is supplied through the down-lock limit switches to the down side of the coils, magnetizing the dials to indicate WHEELS (locked down) position on the indicator. If any or all of the landing gear are not fully locked, up or down, a barber pole condition will appear on the dial to indicate that the gear is in the transit position.

The fourth element of the indicator (flap position) operates on the d-c Selsyn system of remote indication and consists essentially of a magnetic rotor revolving within a coil assembly. The element is wired electrically to the flap transmitter. A change in flap position moves the transmitter rotor and a similar rotor movement occurs in the indicator element. A pointer attached to the indicator rotor moves over a graduated dial giving the flap position. The dial has five positions: UP, HALF, DOWN, and two one-quarter increments. The pointer, however, will indicate any position on the dial corresponding to the flaps position. Should there be an interruption of electrical power to the indicator, OFF will appear in a window in the bottom half of the indicator.

Exhaust Nozzle Position Indicating System

The exhaust nozzle position indicating system (such as that used in the F-4B) provides a visual indication in the pilot's cockpit of the engine variable exhaust nozzle position. This in turn provides a measure of percentage of afterburning since constant temperatures are held throughout the afterburner range. (See fig. 20-12.)

A separate but identical nozzle position indicating system is used for each engine. Each system consists of a transmitter potentiometer in the nozzle area control unit, an indicator on the pilot's main instrument panel, and the interconnecting wiring. Power for the system is supplied from the essential 28 v d-c bus.

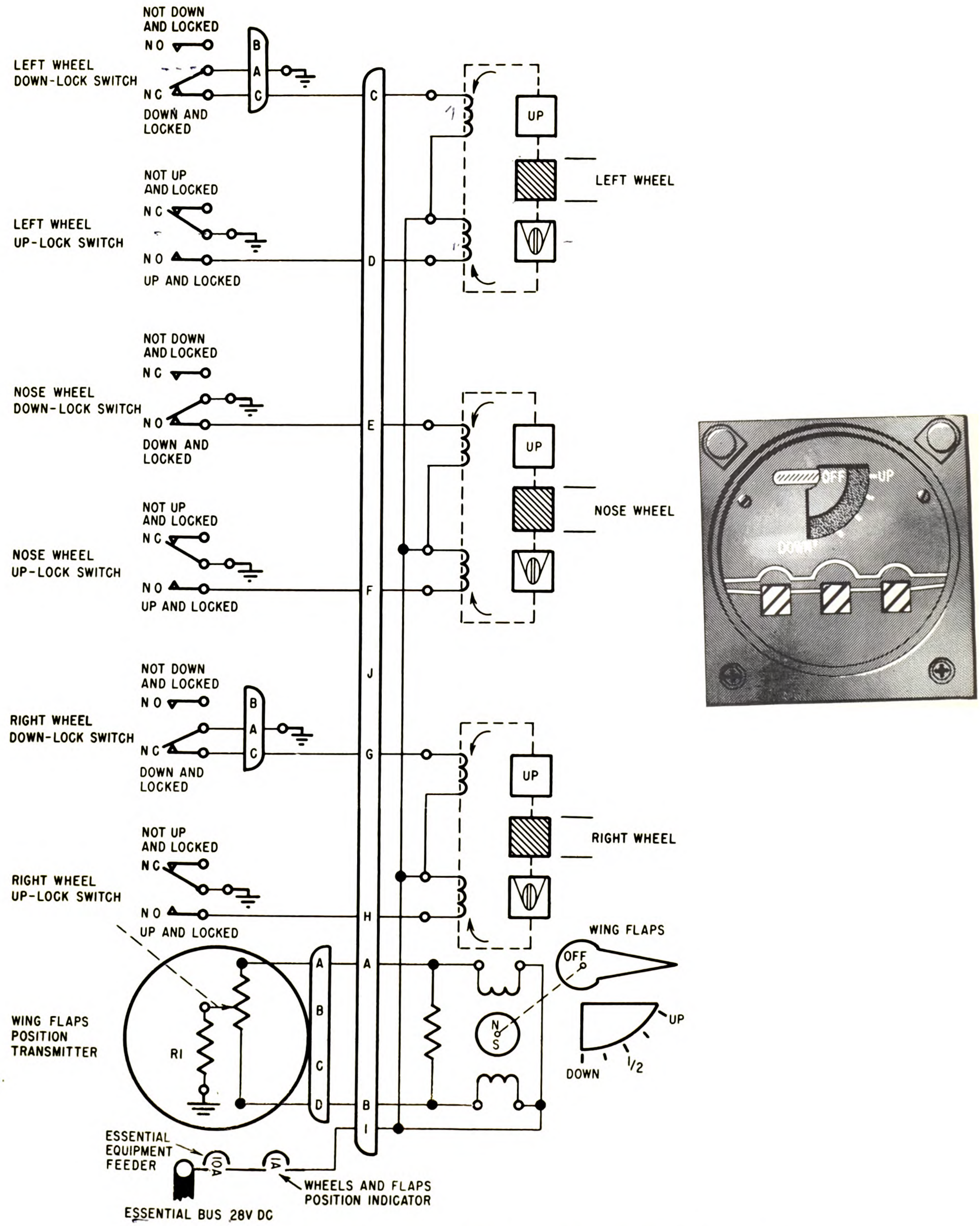


Figure 20-11.—Wheels and flaps position indicating system.

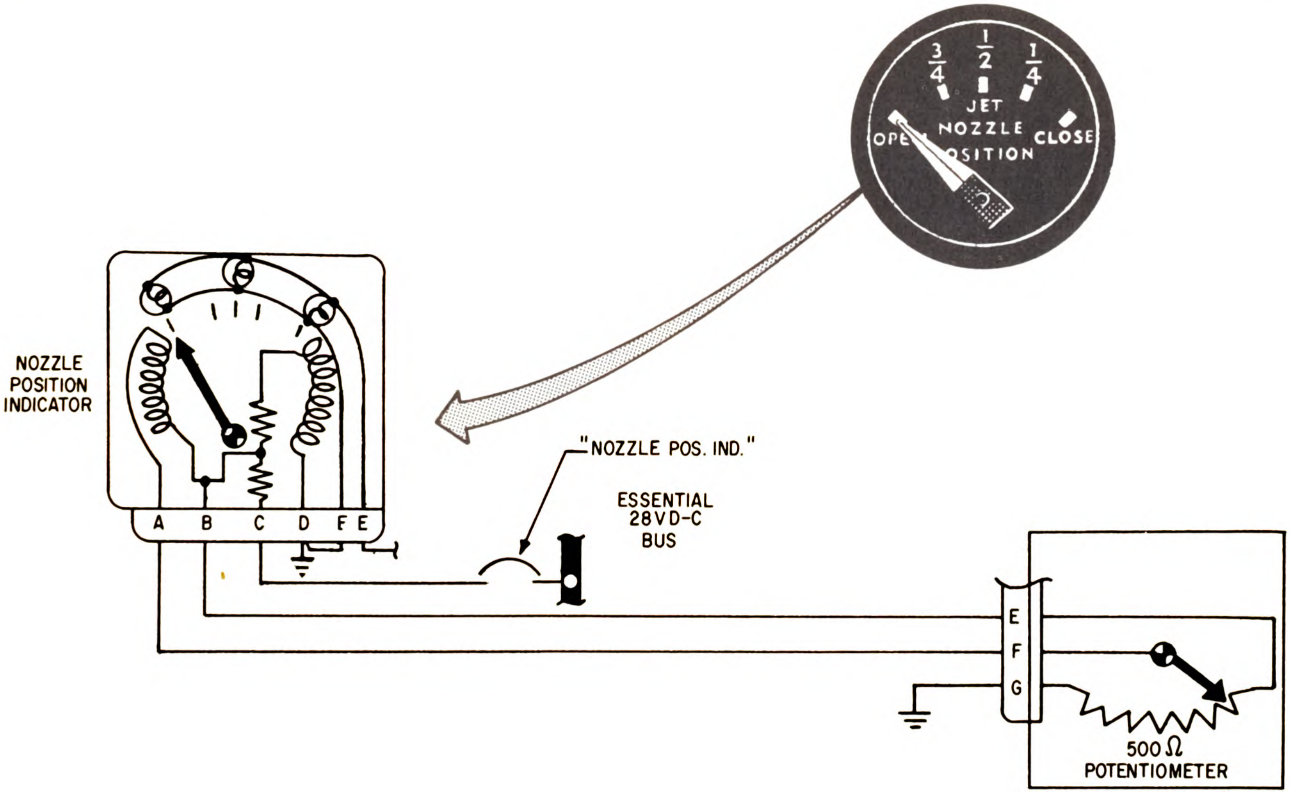


Figure 20-12.—Exhaust nozzle position indicating system.

Each indicator is a hermetically-sealed unit and contains a single receptacle for a mating plug electrical connection. The instrument scale ranges from OPEN to CLOSE with markings at the 1/4, 1/2, and 3/4 positions.

The transmitter potentiometer consists of a resistance winding on which is located a movable brush. This brush is attached to a linkage within the nozzle area control and moves in relationship to the variable exhaust nozzle. Current supplied to the resistance winding is picked up by the movable brush, and varies according to the location of the brush. This signal is then carried to one of the indicator field coils.

The indicator contains two field coils and a rotor. The polarized rotor is mounted on a free moving shaft and is located in the center of the magnetic field created by the two coils. One of the coils is connected to the transmitter potentiometer in the nozzle area control; the other one is supplied with a constant current to give smooth indicator operation. The rotor alines itself with the strength of the magnetic field, which varies in accordance with the signal received from the potentiometer. A pointer mounted on the same shaft as the rotor indicates the position of the rotor in relation to nozzle position.

Magnesyn System

The Magnesyn system is an electrical self-synchronous device used to transmit the direction of a magnetic field from one coil to another. The Magnesyn position system is essentially a method of measuring the extent of the movement of such elements as the wing and cowl flaps, trim tabs, landing gear, and other control surfaces. The two main units of the system are the transmitter and the indicator. (See fig. 20-13.)

The transmitter shaft is connected directly to the surface being measured through a simple linkage, and is electrically connected to the indicator. The leads between the transmitter and the indicator may be of any reasonable length without noticeable effect on the indication.

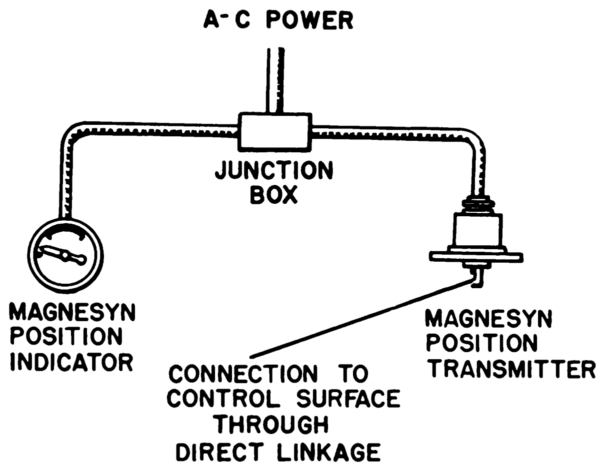


Figure 20-13.—Magnesyn position system.

In a Magnesyn, a soft iron ring is placed around a permanent magnet so that most of the magnet's lines of force pass within the ring. This ring, which may be described as a circular core of magnetic material, is provided with a single continuous electrical winding of fine wire. Figure 20-14 is the electrical wiring schematic of a Magnesyn system. The circular core of magnetic material and the winding are the essential components of the Magnesyn stator. The rotor consists of the permanent magnet.

The position transmitter is composed of a shaft and a Magnesyn (rotor and stator). The movement of the control surface of the aircraft causes a proportional movement of the transmitter shaft. This in turn causes a rotary displacement of the magnet. Varying voltages are set up in the Magnesyn stator, depending on the position of the magnet. The voltages are transmitted to a Magnesyn indicator which indicates on a dial the values received from the transmitter. The indicator consists essentially of a Magnesyn, a graduated dial, and a pointer. The pointer is attached to the shaft and the shaft is attached to the magnet; thus movement of the magnet causes movement of the pointer.

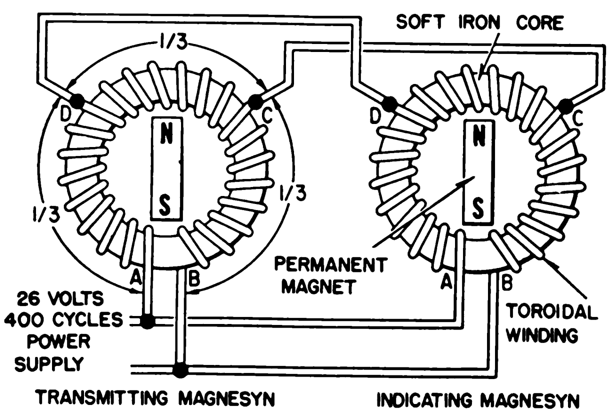


Figure 20-14.—Electrical wiring schematic of a Magnesyn system.

Testing and Adjusting

Testing and adjusting of position indicating instruments is a relatively simple matter because most adjustments are made on a transmitter or limit switch with electrical power on the circuit. For example, when adjusting a flaps position indicator, set the flaps to the UP position, then with the flaps mechanically up, adjust the flaps transmitter until the indicator indicates UP. Testing usually consists of voltage checks and circuit functional checks. Refer to chapter 14 of this course for circuit troubleshooting procedures.

FUEL GAGES

CAPACITOR TYPE FUEL QUANTITY GAGES

The capacitor type fuel quantity gage system is an electronic fuel measuring device that indicates fuel quantity in pounds. The basic components of the system are one or more tank units, a power unit, and an indicator. (See fig. 20-15.)

System Principle

The indicator consists of a small induction motor, a potentiometer, a low-level switch, and a pointer. A change in the fuel quantity of a tank causes a change in the capacitance of the tank unit. This tank unit is one arm of a capacitance bridge circuit. The voltage signal resulting from the unbalanced bridge is amplified by a phase sensitive amplifier in the power unit. This amplified signal energizes

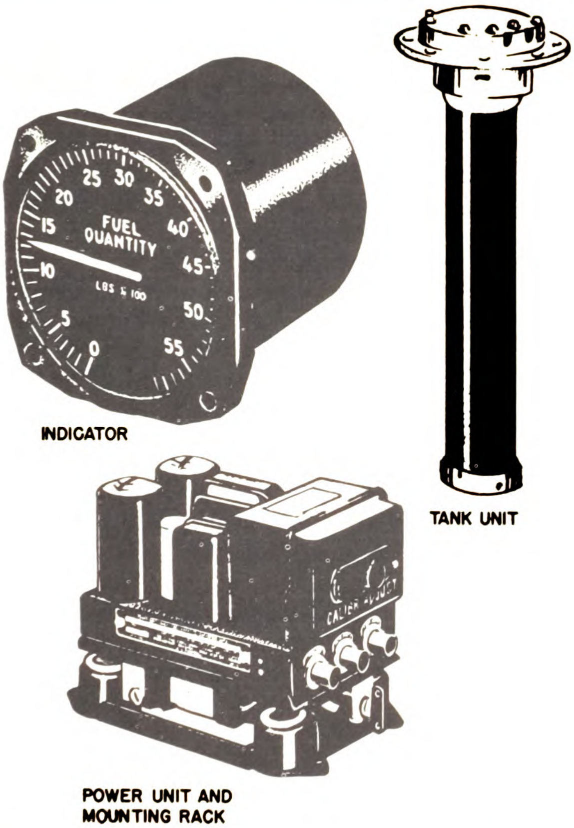


Figure 20-15.—Basic components of a typical capacitor type fuel quantity system.

one winding of a miniature 2-phase induction motor in the indicator. The induction motor drives the wiper of a rebalancing potentiometer in the proper direction to balance the bridge again. At the sametime, it positions an indicator pointer to read the quantity of fuel remaining in the tank.

A simplified version of a tank unit is shown in figure 20-16. The capacitance of a capacitor depends upon three factors; the area of the plates, the distance between the plates, and the dielectric constant of the material between the plates. The only variable factor in the tank unit is the dielectric of the material between the plates. When the tank is full, the dielectric material is all fuel. Its dielectric constant is about 2.07 at 0° C, compared to a dielectric constant of 1 for air. When the tank is half full, there is air between the upper half of the plates and fuel between the lower half. Therefore, the capacitor has less capacitance than it had when the tank was full. When the tank is empty, there is only air between the plates and consequently the capacitance is still less. Any change in fuel quantity between full and empty produces a corresponding change in capacitance.

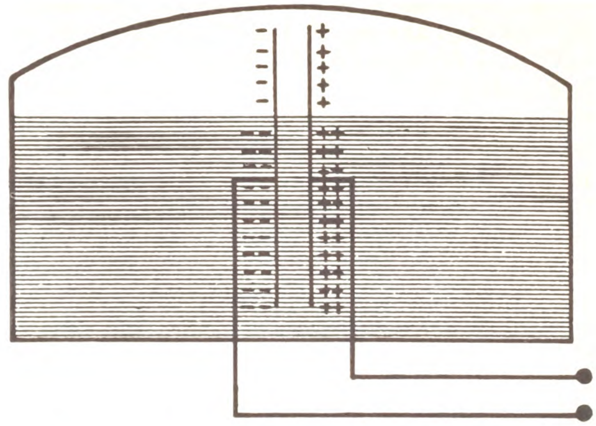


Figure 20-16.—Simplified tank circuit.

System Operation

A simplified capacitance bridge circuit is illustrated in figure 20-17. The fuel tank capacitor and a fixed reference capacitor are connected in series across a transformer secondary winding. A voltmeter is connected from the exact center of the transformer winding to

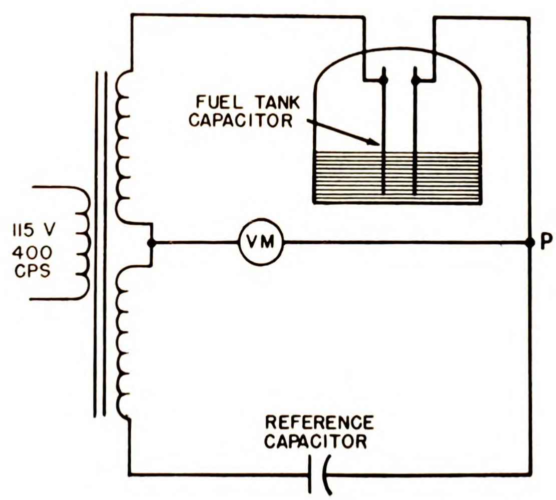


Figure 20-17.—Simplified capacitance bridge circuit.

a point between the two capacitors. If the two capacitances are equal, the voltage drops across them will be equal and the voltage between the center tap and point P will be zero. As the fuel quantity increases, the capacitance of the tank unit increases, causing more current to flow in the tank unit leg of the bridge circuit. This will cause a voltage to exist across the voltmeter that is in phase with the voltage applied to the transformer. If the quantity of fuel in the tank decreases, there will be a smaller flow of current in the tank unit leg of the bridge. The voltage across the voltmeter will now be out of phase with the voltage applied to the transformer.

In an actual capacitor type fuel gage, the input to a two-stage amplifier is connected in place of the voltmeter. It amplifies the signal resulting from an unbalance in the bridge circuit. The output of the amplifier energizes a winding of the 2-phase indicator motor. The other motor winding, called the line phase winding, is constantly energized by the same voltage that is applied to the transformer in the bridge circuit, but its phase is shifted 90° by a series capacitor. As a result, the indicator motor is phase sensitive; that is, it will operate in either direction, depending on whether the tank unit capacitance is increasing or decreasing.

As the tank unit capacitance increases or decreases because of a change in fuel quantity, it is necessary to readjust the bridge circuit to a balanced condition so that the indicator motor will not continue to change the position of the indicating needle. This is accomplished by a balancing potentiometer connected across one-half of the transformer secondary, as shown in figure 20-18. The indicator motor drives this potentiometer wiper in the direction necessary to maintain continuous balance in the bridge.

The circuit shown in figure 20-18 is a self-balancing bridge circuit. An empty-calibrating

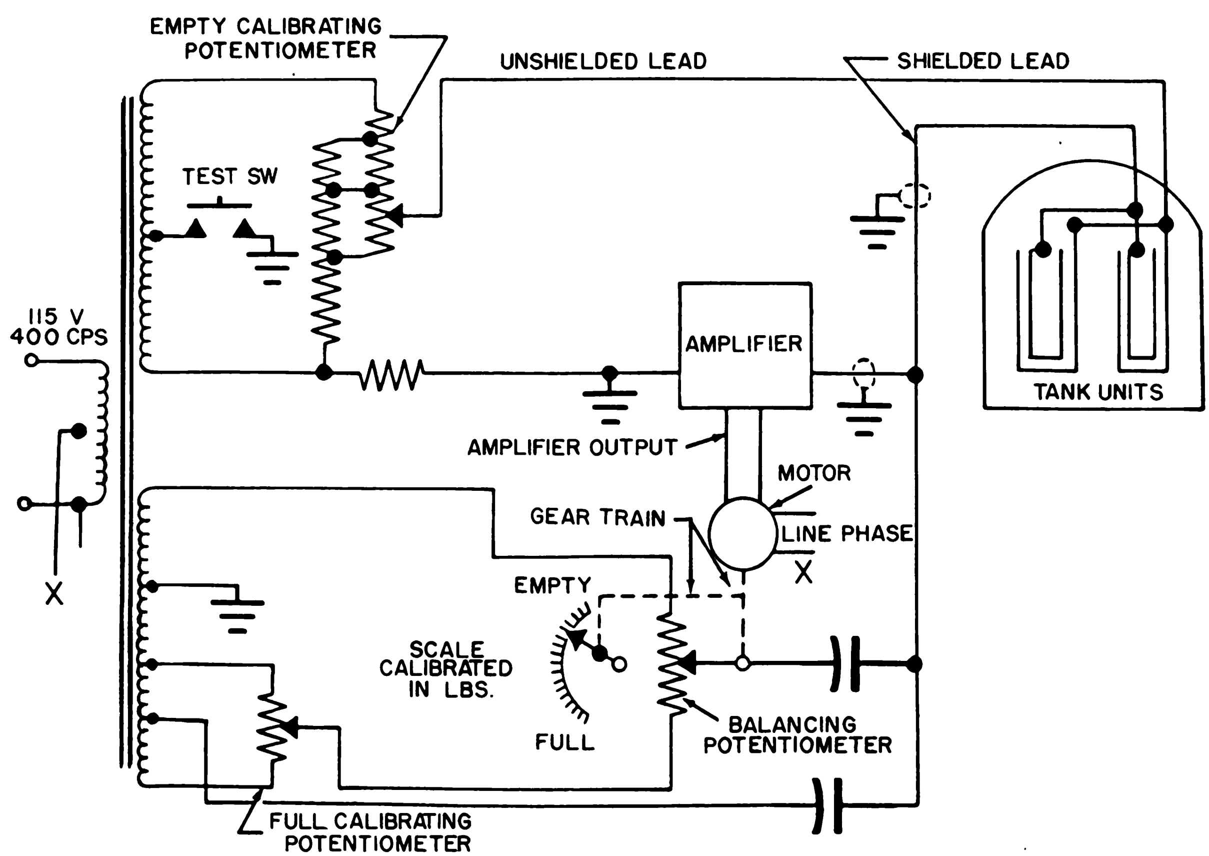


Figure 20-18.—Self-balancing bridge circuit.

potentiometer and a full-calibrating potentiometer are connected across portions of the transformer secondary winding at opposite ends of the winding. These potentiometers may be adjusted so that the bridge voltages balance over the empty-to-full capacitance range of a specific system.

The amplifier is not a part of the measuring circuit. Therefore, the accuracy of the system is independent of tube characteristics in the amplifier. Tubes can be replaced without affecting the calibration of the system. Also, since the system is continuously balancing and operates at the null point, it is independent of voltage and frequency variation in the power supply.

In some installations where the indicator shows the contents of only one tank and where the tank is fairly symmetrical, one unit is sufficient. However, for increased accuracy in peculiarly shaped fuel tanks, two or more tank units are connected in parallel to minimize the effects of changes in aircraft attitude and sloshing of fuel in the tanks.

Since neither electrode of the tank unit is grounded and since one of the leads between the tank unit and amplifier is shielded, the capacitance to ground does not enter into the circuit. Therefore, the length of the tank unit leads does not affect the accuracy of the system. The power unit may be located wherever it is protected from the weather and is accessible for servicing.

The test switch in the top secondary winding is used to unbalance the bridge circuit momentarily when checking the operation of the system. When the switch is closed, voltage is reduced on the tank unit side of the bridge, unbalancing the circuit. As a result, the indicator drives toward the empty end of the dial. Opening the switch should restore the bridge to balance and return the indicator pointer to its original position. This proves that the system is operating correctly.

A low-level warning switch is included in the indicator unit to provide a warning signal when the fuel falls below a certain point (not shown in the figure). It consists of a wiper, isolated from the contact plate by an adjustable insulator which may be positioned to actuate the warning device at any position from 0 (empty) to 150 (about midscale). At the preset scale point, the wiper closes a circuit to the warning device.

Fuel Characteristics

The characteristics of fuel are such that the dielectric constant and density will deviate due to temperature change or due to the variable factor in the composition of the fuel. The weight of aircraft fuel depends upon its density, which, in turn, depends upon its temperature. For example, one aircraft fuel has a density of 6.35 pounds per gallon at 0° C. As the temperature of the fuel goes down, the density increases; and as the temperature of the fuel goes up, the density decreases. Any change in the dielectric constant or density of the fuel will affect the movement of the indicator pointer accordingly. For example, assume that the indicating system is at balance with the tank unit immersed to a given depth in a fuel having the nominal density and dielectric constant of the fuel for which the system is calibrated. The indicator pointer will then reflect the correct mass of fuel in terms of pounds. Now, if the tanks were drained and then refilled to the same level with a fuel having a greater density and dielectric constant, the pointer would tend to move up the scale to a new point of balance. The new reading would be correct only if the effect of the changes in density and dielectric constant were proportional. However, it is known that the effect of the increase in dielectric constant is generally greater than the effect of the increase in density, resulting in an incorrect indication. It is possible to minimize this error by varying the capacitance of the reference capacitor in the leg of the bridge opposite the immersed tank unit.

Compensation

The reference capacitor can be varied by connecting a compensator unit in parallel with the reference capacitor as shown in figure 20-19. The compensator is a tubular electrostatic capacitor which is completely immersed at the lowest usable level of fuel at all times. Thus, the motivating capacitance of the compensator is determined only by changes in the density and dielectric constant of the fuel. The resultant compensator signal is fed into the reference capacitor side of the bridge circuit to balance out undesirable capacitance changes in the tank unit side of the bridge. The end result is that the compensator reduces the

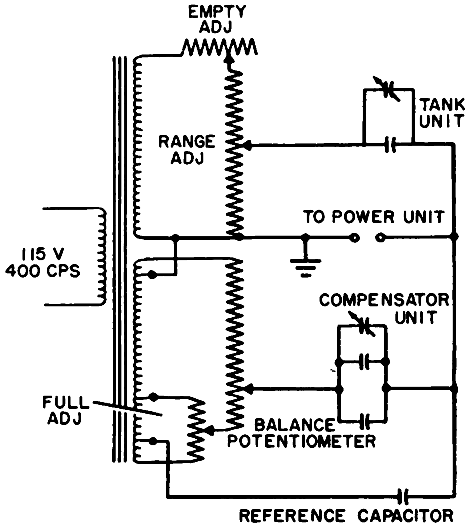


Figure 20-19.—Compensated fuel quantity gage system.

adverse effects of deviations in fuel characteristics and thus provides a more accurate indication of fuel quantity.

There are various capacitor type fuel quantity systems that operate on the principle just described. Indicators, tank units, and power units may differ as to shape, size, and specifications from system to system. Some indicators are equipped with a dial that has a multiplication factor of 1,000 (LBS x 1,000). Also, in some systems the indicator and power unit are enclosed in the same housing. Always consult the manufacturer's manuals for specific information on a particular system.

TEMPERATURE INDICATORS

Various temperature indications must be known in order for an aircraft to be operated properly. It is important that the temperature of the engine oil, carburetor mixture, carburetor air, free air, engine cylinders, heater ducts, and exhaust systems of jet engines be known; many other temperatures must be known also, but these are some of the more important ones. Different types of thermometers are used to collect and present this information.

BIMETAL THERMOMETER

This type thermometer operates on the principle of using two different metals which expand and contract at different rates when heated or cooled the same amount. Almost all solid materials expand when heated. The materials that do expand have been assigned values to indicate their expansion rates. These values are represented by numbers called the coefficient of expansion. For example, iron and brass have coefficients of expansion which indicate that brass expands more than iron when heated the same amount.

Suppose two strips of metal, one brass and the other iron, are fastened together as in figure 20-20 (A). At average room temperature, it is assumed, the lengths of the two strips are the same. As the strips are heated—or as the temperature of the room increases—the length of the brass strip increases more than the length of the iron strip, and the bimetal strip curves as shown in figure 20-20 (B). When the temperature falls, the brass strip contrasts more than the iron, and the curvature will be reversed as shown in figure 20-20 (C).

A thermometer of the bimetal type may be constructed by fastening an indicator pointer to one end of the bimetal strip and attaching the other end of the strip rigidly to an instrument case. A dial marked in degrees of temperature is placed behind the indicator pointer.

Many of the outside air thermometers used on naval aircraft are the bimetal type. They have a range of -40°C to +40°C, and are mounted outside the cockpit in such a manner that the dial is clearly visible to the pilot. The cases of these thermometers are designed so as to offer the least possible airflow resistance, and should be installed with the face parallel to the force-and-aft axis of the aircraft at a point relatively free of vibration. Since the outsides of the cases are chromium plated to reflect heat

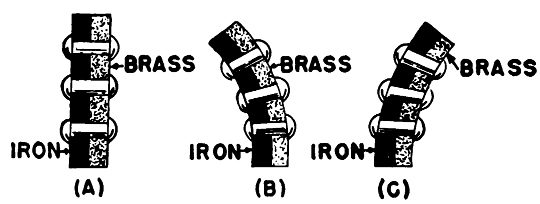


Figure 20-20.—(A) Bimetal strip at room temperature; (B) after heating; (C) after cooling.

from other sources than the air, they should not be marred or painted.

The bimetal strip in some thermometers is in a spiral shape, as shown in figure 20-21. The pointer shaft is attached directly to the bimetal strip at the center of the spiral.

If a check of the instrument shows that the readings are incorrect, it can be reset by removing the cover at the front of the dial. (See fig. 20-22.) Remove the pointer by means of a pointer jack, or by slipping two small screwdrivers under the pointer on opposite sides of the shaft and lifting the pointer off. Then replace the pointer in the correct position. Do not disturb the bimetal strip. Its proper length is fixed at the factory, and it is, therefore, permanently adjusted. This type of maintenance is usually performed only in an instrument repair shop.

These thermometers are used to indicate temperatures at remote points in the aircraft.

Figure 20-21.—Bimetal spiral in outside air thermometers.

Figure 20-22.—Bimetal thermometer dial.

The main parts of the electrical resistance thermometer are as follows:

1. The indicating instrument.
2. The temperature-sensitive element (resistance bulb).
3. The connecting wires leading from the bulb.

The indicator dials of these thermometers are calibrated in accordance with the range of temperature to be measured. Figure 20-23 shows an electrical resistance thermometer indicator. The indicators are self-compensated for changes in cockpit temperature.

The operation of this type thermometer is based on the scientific fact that most metals change their electrical resistance with changes in temperature. In almost every case, the electrical resistance of a metal increases as the temperature rises. The resistance of some metals increases more than the resistance of others with a given rise in temperature. An electrical resistance thermometer is a metallic resistor with a high temperature-resistance coefficient (a high rate of resistance rise for a given increase in temperature). A resistance indicator is connected to it.

The heat-sensitive resistor (fig. 20-24) is the main element in the bulb. It is made so that it has a definite resistance for each temperature value in its working range. The indicator is a resistance-measuring instrument with its dial calibrated in degrees of temperature instead of ohms.

Two types of resistance bulb thermometers are used in aircraft. They are the Wheatstone bridge type and the ratiometer type.

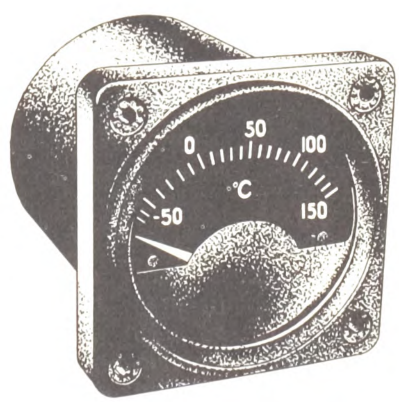


Figure 20-23.—Indicator of an electrical resistance thermometer.

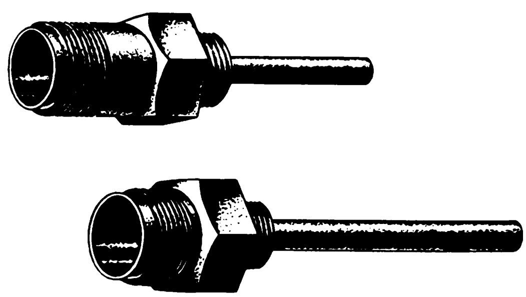


Figure 20-24.—Resistance thermometer bulb assemblies.

Wheatstone Bridge Thermometer

A schematic diagram of a Wheatstone bridge thermometer circuit is shown in figure 20-25. The resistance bulb element is one of the sides of the Wheatstone bridge circuit. The other three sides are resistors that are contained in the indicating meter. Voltage is applied to the circuit from the d-c power supply in the aircraft.

When the temperature bulb is exposed to a temperature of 0° C, its resistance is 100 ohms. The resistance of arms X, Y, and Z are also 100 ohms each. At this temperature, therefore, the Wheatstone bridge is balanced. This means that the resistance of X and Y added together equals the resistance of the bulb and Z. Therefore, the same amount of current flows in both sides of this parallel circuit. Since all four sides are equal in resistance, half of the applied voltage is dropped across side X and also across the bulb. The voltages at points A and B are, therefore, equal. Since these voltages are equal, the voltage from A to B is zero. Therefore, the indicator reads zero. It is important

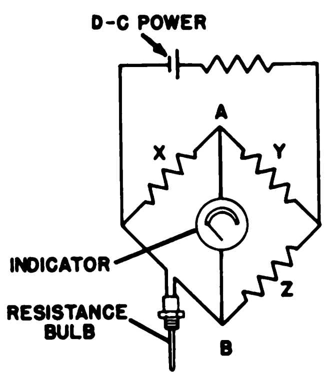


Figure 20-25.—Wheatstone bridge thermometer.

to note that if there is an open in the external circuit, the galvanometer will also read zero.

When the temperature of the bulb increases, its resistance also increases. This unbalances the bridge circuit and causes the needle to be deflected to the right. When the temperature of the bulb decreases, its resistance decreases. Again the bridge circuit is unbalanced, but this time it causes the needle to be deflected to the left.

The galvanometer has been calibrated so that the amount of deflection either to the right or to the left causes the needle to point to the number on the meter scale that corresponds to the temperature at the resistance bulb, wherever it may be located.

This instrument requires a consant and steady supply of d-c voltage, since the bridge imbalance is directly affected by fluctuations in the total bridge current. Unless the bulb is damaged by excessive heat, it will give accurate service indefinitely. If it is damaged by too much heat, it should be replaced. When a thermometer will not operate properly, check carefully for loose wiring connections before replacing the bulb.

Ratiometer

The ratiometer type of temperature indicator uses two coils in a balanced circuit instead of resistors as in the Wheatstone bridge type. In some instruments, these coils are designed to turn between the poles of a permanent magnet. In other instruments of this type, a small permanent magnet rotor turns between the stationary poles. Different ratiometer circuits vary in design, but the principle of operation of all is very much the same.

A simplified circuit of the type with the permanent magnet rotor is illustrated in figure 20-26. The two coils are fixed in the instrument, and the indicator needle is fastened to the permanent magnet rotor. The position of the needle is determined by how the small permanent magnet alines itself with the resultant flux of the two coils.

For an understanding of how the circuit operates, trace the current through the circuit. Starting at ground, current flows up through the bulb, centering potentiometer R5, and R6 to point D. Current through the left leg of the bridge is from ground through R1 to point A; from point A through the lower part of the expansion and contraction potentiometer R2;

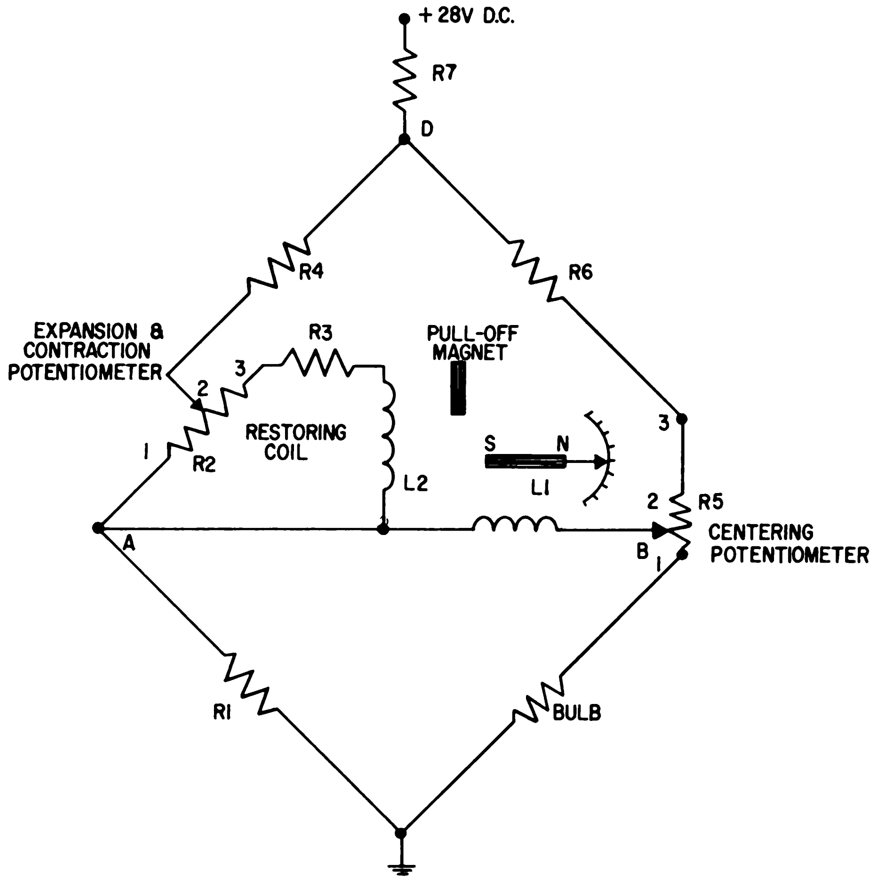


Figure 20-26.—Ratiometer type temperature indicator.

and from pin 2 of R2 through R4 to point D. Here the current of the two legs combine and flow through R7 to the positive 28 volts.

It should be noted that restoring coil L2, resistor R3 and the upper part of potentiometer R2 form a parallel path for current flow from point A to pin 2 of R2. Deflection coil L1 is connected between points A and B; therefore any difference in potential between these two points will cause current to flow through L1.

The ratiometer type temperature indicator utilizes a permanent magnet rotor and a fixed permanent magnet to pull the pointer to an off position when the indicator is not operating. Thus, current through the restoring coil L2 must compensate for the pulloff magnet when the indicator is operating. Variations in the resistance of the bulb, due to temperature changes, will cause a change in voltage at point B and a resulting change in current through the deflection coil L1.

THERMOCOUPLE INDICATORS

Thermocouple temperature indicators are used to indicate the temperature of the engine cylinders, the air temperatures in the heater duct of anti-icing systems, and the exhaust system of jet engines.

A thermocouple is a junction or connection of two unlike metals; such a circuit has two junctions. If one of the junctions is heated to a higher temperature than the other, an electromotive force is produced in the circuit. By including a galvanometer in the circuit, this electromotive force can be measured. The hotter the high-temperature junction (hot junction) becomes the greater the electromotive

force produced. By calibrating the galvanometer dial in degrees of temperature, it becomes a thermometer.

The thermocouple thermometer systems used in naval aircraft consist of a galvanometer type indicator, a thermocouple or thermocouples, and thermocouple leads. Some thermocouples are made up of a strip of copper and a strip of constantan that are pressed tightly together. Constantan is an alloy of copper and nickel. Other thermocouples are made up of a strip of iron and a strip of constantan or a strip of chromel and a strip of alumel. Iron-constantan is used mostly in radial engine aircraft; chromel-alumel is used with jet aircraft.

The "hot" junction of the thermocouple varies in shape depending on its application. Two common types are shown in figure 20-27; they are the gasket type and the rivet type. In the gasket type, two rings of the dissimilar metals are pressed together to form a spark plug gasket. Each lead that makes a connection back to the galvanometer must be made of the same metal as the part of the thermocouple to which it is connected. For example, a copper wire is connected to the copper ring and a constantan wire is connected to the constantan ring. The rivet type thermocouple is shown installed in the cylinder wall. Here

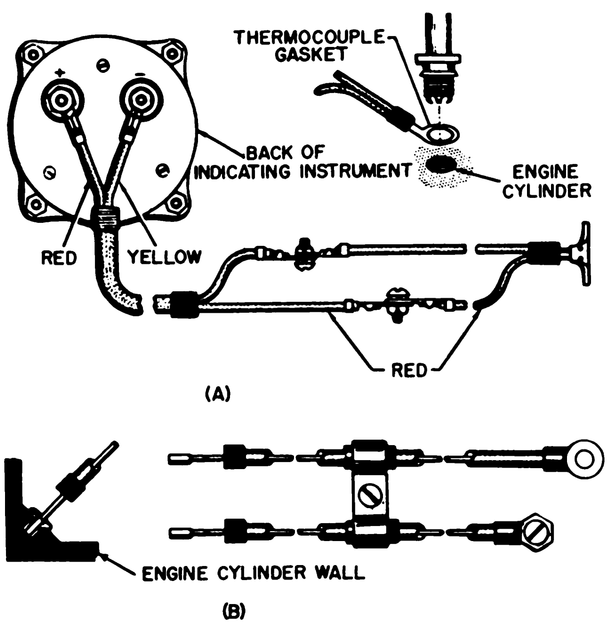


Figure 20-27.—Thermocouples.
(A) Gasket type; (B) rivet type.

again, the same metal is used in the lead as in the part of the thermocouple to which it is connected.

Cylinder Head Indications

The cylinder chosen for installing the thermocouple is the one which runs the hottest under most operating conditions. The location of this cylinder varies with different engines. Thermocouples are also installed on auxiliary powerplants to measure cylinder temperatures.

Dual cylinder temperature indicators are provided for multiengine aircraft. These are two separate indicators in one case. Each is connected to a separate thermocouple. One thermocouple is required for each indicator. In some cases, several thermocouples may be connected to a single indicator meter by using a selector switch.

The "cold" junction of the thermocouple circuit is inside the indicator instrument case. Since the electromotive force set up in the circuit varies with the difference in temperature between the "hot" and "cold" junction, it is necessary to compensate the indicator mechanism for changes in cockpit temperature which affect the "cold" junction. This is accomplished by means of a bimetallic spring—much like the one in a bimetal air thermometer—that is connected to the indicator mechanism. When the thermocouple lead is disconnected from the indicator, the latter will indicate the temperature of the cockpit. This occurs because, even though the thermocouple is not working, the bimetallic compensator spring keeps on functioning as a thermometer.

Figure 20-28 shows the dials of two thermocouple temperature indicators. The instrument shown at (A) is used to indicate the exhaust temperature of jet engines and reads to 1,000°C. Cylinder head temperature is indicated by the instrument shown at (B); it reads to 300° C.

Turbine Inlet Temperature Indicator System

Aircraft such as the P-3 utilize an engine turbine inlet temperature indicator system to provide a visual indication in the pilot's cockpit of the temperature of gases entering the turbine. The temperature of each engine turbine inlet is measured by 18 dual unit thermocouples installed in the turbine inlet casing. One set of these thermocouples are

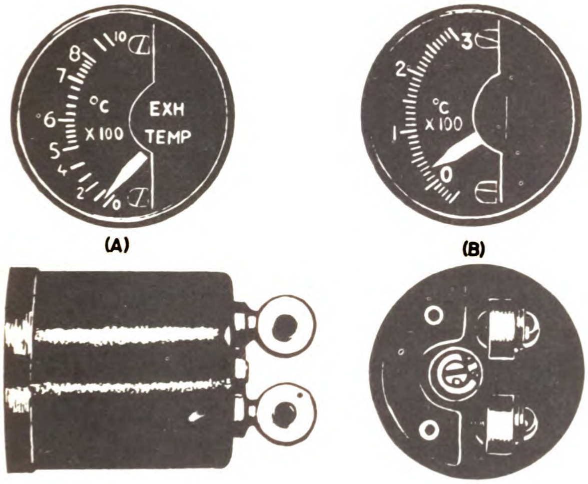


Figure 20-28.—Thermocouple temperature indicators.

paralleled and transmit signals through a harness and aircraft wiring to an indicator. The other set of thermocouples is also paralleled and provides signals to the temperature datum control. Each circuit is electrically independent and provides dual system dependability. (See fig. 20-29.)

All parts of the engine temperature measurement system are made of chromel and alumel material, including welds. Special wiring and wire identification are installed in the aircraft from the thermocouple harness terminal block to the indicator. Plugs in the thermocouple circuits are also special type. The thermocouple harness mounts on the turbine unit aft of the thermocouple. The harness includes separate leads for each of the 18 thermocouples, and maintains two electrically separate circuits. The harness is enclosed in a rigid metal, channel type housing and cover. The leads and terminals project through holes in the front side of the housing wall. Electrical signals from the 18 dual junction thermocouples are averaged within the harness.

The thermocouple assemblies are installed on pads provided around the turbine inlet case. Each thermocouple incorporates two electrically independent junctions within a sampling type probe. Alumel terminal studs are identified by AL and chromel terminal studs by CR stamped adjacent to the studs.

Since the average voltage of the thermocouples at the thermocouple terminal blocks represents the turbine inlet temperature, it is necessary that no interference with the signal take place while the signal is transmitted to the indicator. Therefore, the wiring from the thermocouple terminal block to the indicator is routed through the sensitive harness. Sensitive harness wiring is routed separately from other interference producing wiring.

The indicator contains a bridge circuit with cold junction compensation, a 2-phase motor to drive the pointer, and feedback potentiometer. Also included in the indicator is a Zener voltage reference circuit, a chopper circuit, an amplifier, a power supply, a power off flag, and an overtemp warning light.

Output of the bridge circuit is fed to the chopper circuit so as not to load the bridge circuit. The chopper output is fed to the amplifier. Output of the amplifier feeds the variable field of a 2-phase motor which positions the indicator main pointer and the digital indicator. The motor also drives the feedback potentiometer to provide a nulling signal relative to the temperature signal to stop the drive motor when correct pointer position is reached.

The Zener diode circuit provides a closely regulated reference voltage in the bridge to avoid error from input, voltage variation to the indicator power supply. The indicator power supply provides power to the Zener circuit, the chopper, the amplifier, the power off warning flag, and the fixed field of the 2-phase motor.

The over-temperature warning light in the indicator comes on when the turbine inlet temperature (TIT) pointers is at 977° C (1,790.6° F). At this point a switch in the indicator is closed to energize the warning light. One test switch installed external to the indicators enable the crew to test all of the indicator over-temperature warning lights at the same time. When the test switch is operated to the test position, an over-temperature signal is simulated in each indicators temperature control bridge circuit.

When power to an indicator is interrupted, a red warning flag at the indicator becomes visible. The indicator pointers maintain their position and the over-temperature warning light becomes inoperative. Power for each indicator is obtained from the forward load center 115 v a-c bus through four 1-ampere circuit breakers.

The indicator scale is calibrated in degrees C from 0 to 12 (times 100° C). The digital

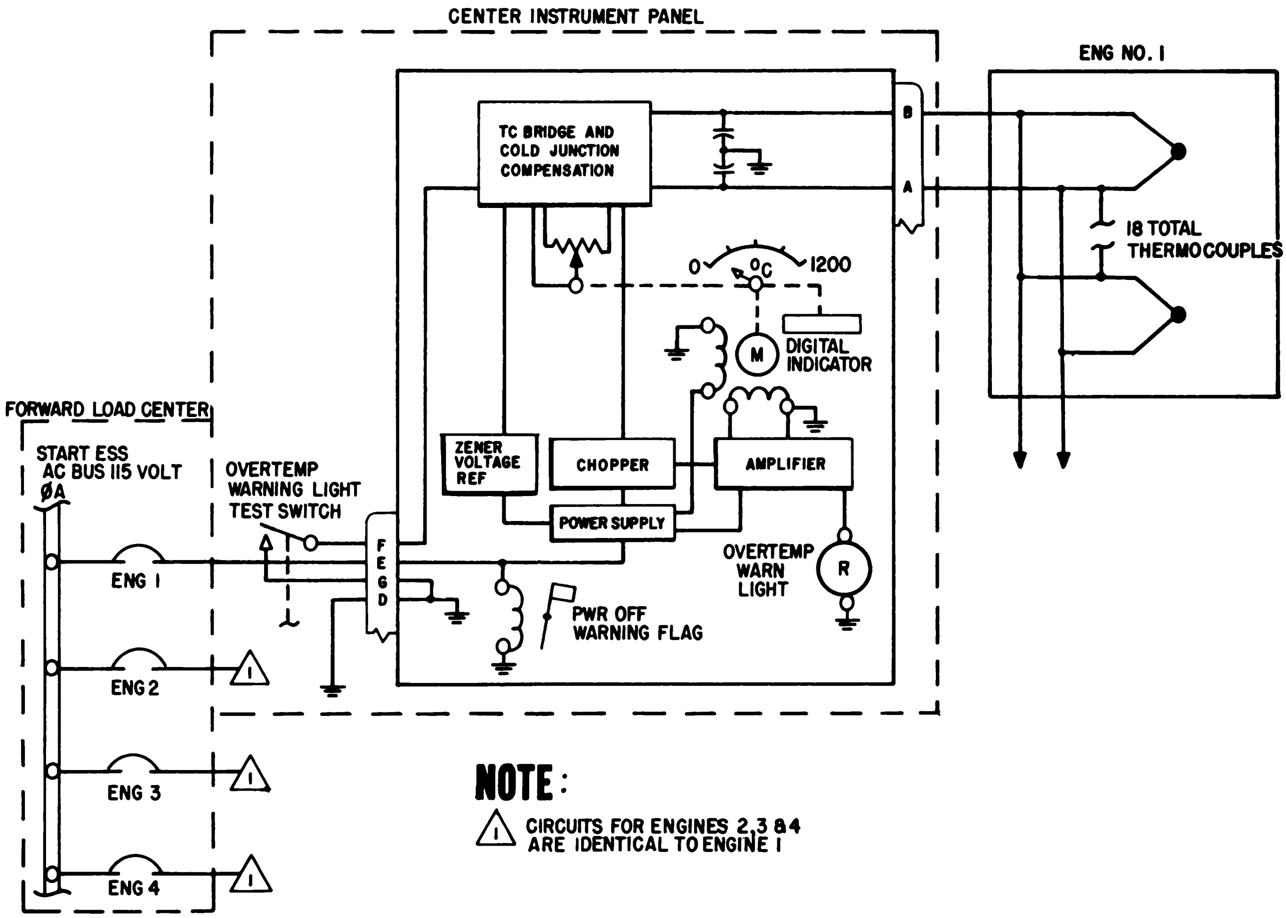


Figure 20-29.—Turbine inlet temperature indicator system.

indicator is calibrated from 0° to 1,200° C in 2° C increments.

Exhaust Gas Temperature Indicating System

The exhaust gas temperature indicating systems provide a visual temperature indication in the pilot's cockpit of the engine exhaust gases as they leave the turbine unit. A typical exhaust gas temperature indicating system, such as used on the F-4B is discussed.

Two separate but identical exhaust gas temperature indicating systems, one for each engine, are utilized in this aircraft. Each system consists of 12 dual thermocouples located on the engine turbine frame, a combination indicator and transistorized amplifier located on the pilot's main instrument panel, and the interconnecting chromel and alumel leads. Power for the indicator-amplifier is supplied from the essential 115 v a-c bus. (See fig. 20-30.)

Both exhaust gas temperature indicators are located on the pilot's main instrument panel and provide a visual indication of the engine exhaust temperatures. Each instrument is a hermetically-sealed unit and contains a single receptacle for a mating plug electrical connection. The instrument scale ranges from 0° to 1,200°, with a vernier dial in the upper right corner of the instrument face. A power off warning flag is located in the lower portion of the dial.

Internally the indicator contains a simulated thermocouple cold junction with compensating resistors, a reference voltage source, d-c to a-c modulator, a transistor power output stage,

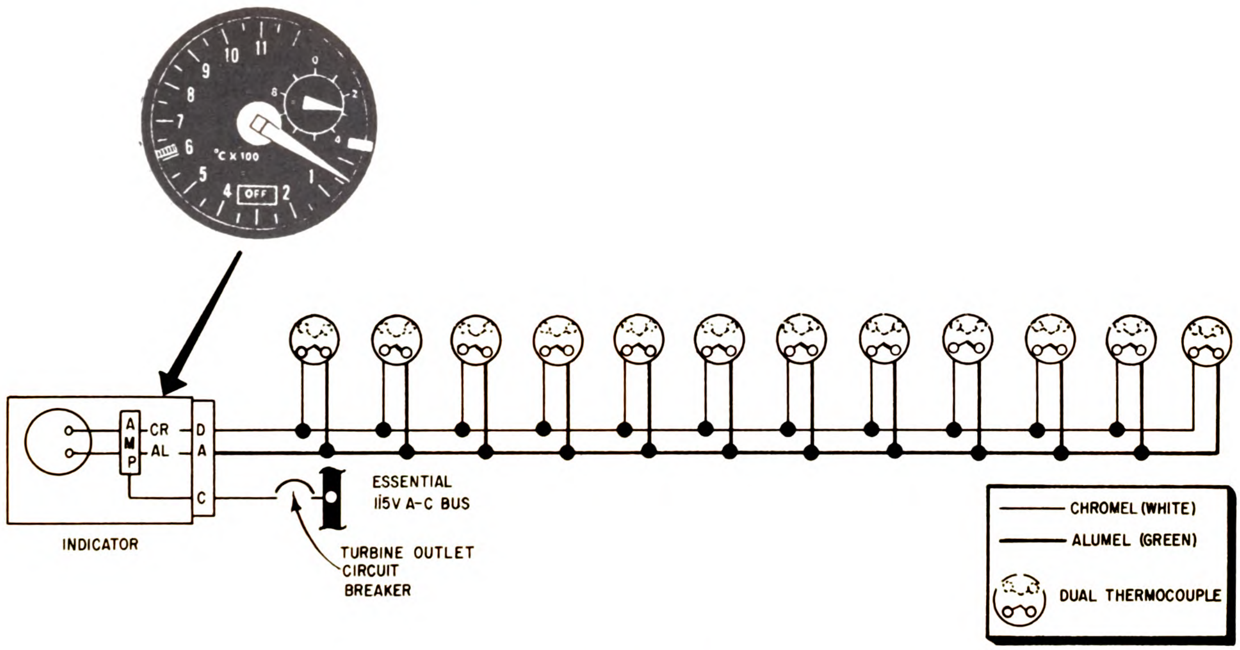


Figure 20-30.—Exhaust gas temperature indicating system.

miniature a-c servomotor, and the power off warning flags. The exhaust gas temperature indicators contains range markings on the instrument faces.

The thermocouples convert engine exhaust gas temperature into millivolts. The voltage produced by the thermocouples is transmitted directly to the indicator-amplifier by the chromel and alumel leads. The voltage is amplified and used to drive a small servomotor, which in turn drives the indicator pointer. The thermocouple harness is made up of two halves, each containing six dual loop thermocouples. The assembled halves make up two independent thermocouple systems each consisting of 12 thermocouples connected in parallel. The harness is mounted to the turbine frame aft of the turbine rotor.

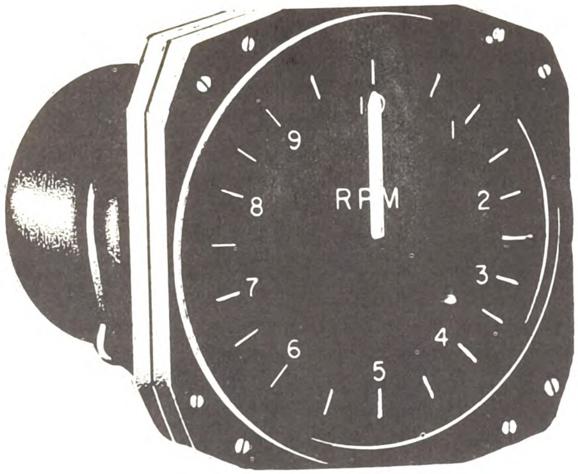
TACHOMETERS

The tachometer indicator is an instrument for indicating the speed of the crankshaft of a reciprocating engine and the speed of the main rotor assembly of a gas turbine (jet) engine.

The dials of tachometer indicators that are used with reciprocating engines are calibrated in revolutions per minute (rpm); those used with jet engines are calibrated in percentage of rpm's being used, based on the takeoff rpm. Figure 20-31 shows a typical dial for each of the indicators just described.

A number of different types of generators and indicators are used in the tachometer system of naval aircraft. Generally speaking, all operate on the same basic principle. In presenting information on tachometer systems a typical generator and a typical indicator are described. It is not practical to describe all of the generators and indicators in a training course such as this; for detailed information on a particular system refer to the manufacturer's manuals.

The tachometer system to be described consists essentially of a 3-phase a-c generator coupled to the aircraft engine, and an indicator consisting of a magnetic-drag element mounted on the instrument panel. The generator transmits 3-phase electric power to a synchronous motor, which is a part of the indicator. The frequency of this power is proportional to the engine speed. By applying the magnetic-drag principle to the indicating element, an accurate indication of the engine speed is obtained. The problem of changes in generator-output voltage is eliminated by the generator



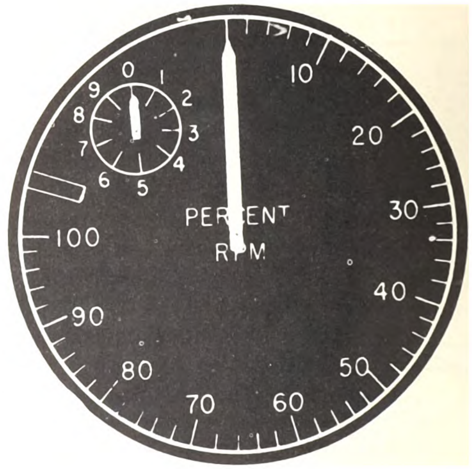


Figure 20-31.—Tachometer dials. (A) Reciprocating engines; (B) jet engine.

and synchronous-motor combination, which constitutes a frequency-sensitive system for transmitting an indication of engine speed to the indicator with absolute accuracy.

For many installations, it is desirable to transmit a single engine-speed indication to two different stations in the aircraft. The frequency-sensitive system is ideal for this application since there is no change in indication when a second indicator is connected in parallel with the first. Synchronous-motor operation in each indicator is dependent only upon the availability of sufficient power in the generator to operate both indicator motors.

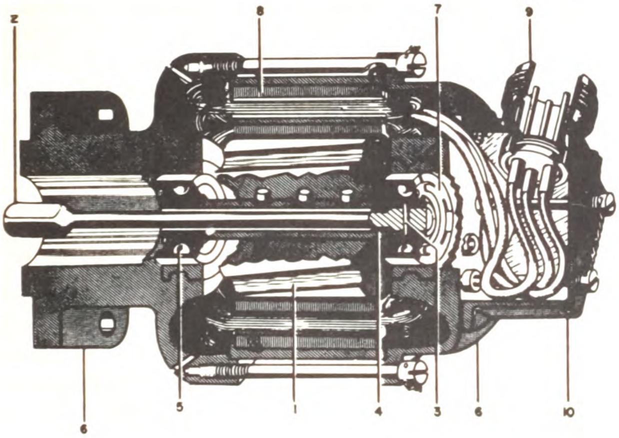
TACHOMETER GENERATOR

Tachometer generator units are small and compact (about 4 inches by 6 inches), and are available in three types known as the pad type, swivel-nut type, and the screw type. These names refer to the kind of mounting used in attaching the generator to the engine. The pad type generator is constructed with an end shield designed so that the generator can be attached to a flat plate on the engine frame, or reduction gearbox, with four bolts. The swivel-nut type generator is constructed with a mounting nut which is free to turn with respect to the rest of the instrument. This type of generator can be held stationary while the mounting nut is screwed into place. The screw type generator is constructed with a mounting nut inserted in one of the end shields. The mounting nut is a rigid part of the instrument, and it is necessary to turn the whole generator when screwing the nut onto its mating thread.

Figure 20-32 shows the cutaway view of a typical tachometer generator. The generator consists essentially of a permanent-magnet rotor (1) driven by the engine, and a stator (8) in which 3-phase power is developed as the rotor turns.

The armature of the generator consists of a magnetized rotor which has been cast directly onto the generator shaft. The generator may be of either two- or four-pole construction. The two- and four-pole rotor are identical in appearance and construction, and differ only in that the two-pole rotor is magnitized north and south diametrically across the rotor, while the four-pole rotor is magnetized alternately north and south at each of the four-pole faces.

The key (2) which drives the rotor is a long slender shaft which has sufficient flexibility to prevent failure under the torsional oscillations originating in the aircraft drive shaft, as well as to accommodate small misalinements between the generator and its mounting surfaces. This key is inserted into the hollow rotor shaft and is secured in place by means of a pin (3) at the end opposite the drive end. An oil-seal



1. Rotor.
2. Drive key.
3. Pin.
4. Oil-seal ring.
5. Ball bearings.
6. End shields.
7. Adjusting spring.
8. Stator.
9. Receptacle.
10. Junction box.

Figure 20-32.—Cutaway view of a tachometer generator.

ring (4) is placed inside the hollow shaft and over this key to prevent leakage of oil into the generator through the hollow shaft. The shaft runs in two ball bearings (5) set in stainless steel inserts which are cast directly into the generator end shields (6). An adjusting spring (7) is set at the receptacle end of the shaft to maintain the proper amount of end play.

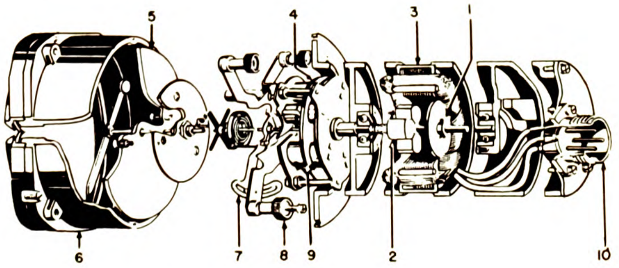
The stator consists of a steel ring into which a laminated core of ferromagnetic material is placed. A 3-phase winding is inserted around this core and is properly insulated from it. The winding is adapted for two- or four-pole construction, depending on the generator in which it is used. The two end shields are made of diecast aluminum alloy, and serve to support the generator stator and rotor. Connections are made to the 3-phase stator by means of a receptacle (9) which is attached to the junction box (10) of the generator. The generator and indicator are connected electrically with a cable that is equipped at each end with mating plugs that fit into the receptacles on both the units.

TACHOMETER INDICATOR

Tachometer indicators are usually mounted on the instrument panel in the cockpit. They are relatively small in size being about 5 inches long and 4 inches wide. These units vary as to type, depending on the particular installation; some are single-element tachometer indicators and others are dual-element tachometer indicators. The operating principles of the two types are basically the same.

Figure 20-33 shows the cutaway view of a typical single-element tachometer indicator. The unit consists essentially of two parts: A sysnchronous motor, which runs in synchronism with the tachometer generator; and an indicating element, which is driven by the motor through a magnetic-drag coupling. The indicating element indicates the speed of the synchronous motor and, therefore, the speed of the aircraft engine.

The synchronous motor (3, fig. 20-33) consists of a 3-phase stator winding which is inserted in, and insulated from, a laminated circular core. Within the circular core is a shaft to which the rotating parts are attached. A hysteresis disk (1) is secured to the shaft by a cotter pin. A permanent magnet rotor (2) is free to move on the shaft, and is restrained from longitudinal motion at one end by the hysteresis disk, and at the other end by a spring which is secured to the shaft for the purpose of transmitting torque from the rotor to the shaft. Ball bearings are inserted in the motor end shields to support the shaft. These end shields also serve to locate the stator so that all of the parts of the motor will maintain their proper position with respect to each other.



1. Hysteresis disk.
2. Rotor.
3. Motor.
4. Drag disk.
5. Scale plate.
6. Cover assembly.
7. Adjusting arm.
8. Adjusting nut.
9. Magnet assemblies.
10. Receptacle.

Figure 20-33.—Cutaway view of a tachometer indicator.

The armature of the synchronous motor consists mainly of the permanent magnet and the hysteresis disk. The purpose of the permanent-magnet material is to provide starting and running torque at low speeds when the magnitude of flux is low. The purpose of the hysteresis disk is to provide starting torque at high speed when the magnitude of flux is great but where the permanent magnet, by itself, will not pull into step. At the higher speeds, the hysteresis disk moves the rotor up to near synchronism and then the permanent magnet pulls it into exact synchronism.

One end of the motor shaft extends through the front end shield and supports the drag-magnet assembly (9). The drag-magnet assembly, which is driven by the synchronous motor, consists of two plates to which small permanent magnets are attached. The magnets are arranged to concentrate the flux near the outside edge of the drag disk in order to obtain the maximum amount of torque with a minimum of weight. Between the two plates carrying the magnets is a disk (4) of conducting material. This material is an alloy having a low temperature coefficient so that its resistance will not be greatly affected by temperature changes. As the magnet assembly spins around this disk of conducting material, it produces torque on the disk.

The drag disk is connected to the lower end of the shaft of the indicator assembly. When the disk rotates, the indicator pointer moves to indicate the speed of the aircraft engine. The indicating element is supported by three posts on which adjusting nuts (8) are placed for the purpose of leveling the assembly as required. Further positioning is obtained by the adjusting arm (7).

The scale plate (5) is calibrated in rpm or percent and indicates the speed of the engine. The cover assembly (6) serves as a protective container for the mechanism. Electrical connection to the tachometer generator is provided by the receptacle (10) located at the rear of the indicator.

Dual Tachometer

With the increasing necessity of more and more instruments for efficient flight, the combination of several instruments in one has become very common. The dual tachometer is an example of this combining of instruments and is used with multiengine and turbojet aircraft.

The dual tachometer consists of two synchronous-motor-magnetic-drag tachometer indicators housed in a single case. The indicators show simultaneously on a single dial the speeds of rotation of the engines. One tachometer indicator is used for each pair of engines or turbojets of the aircraft.

In multiengine aircraft the tachometer generator located on the engine may be used to generate the synchronizing voltage used by the propeller synchronizing system. This causes the automatic propeller pitch adjustment of each propeller to be varied so that all the engines are running at the same speed, which minimizes vibration in the aircraft. If one engine tends to speed up, the output frequency of its tachometer generator increases. This increased frequency causes the automatic mechanism in the propeller hub to increase the pitch of the blades. The blades then take bigger "slices" of air and increase the load on the engine, causing it to slow down again. This automatic operation is continuous so that there is not actual fluctuation of the engine speed.

TACHOMETER MAINTENANCE

Tachometer systems should be checked prior to each flight. The indicators should be checked for chipped scale markings, loose glass, and loose pointers. The difference in indication between readings taken before and after light tapping should not exceed approximately plus or minus 15 rpm. Both the generator and indicator should be inspected for tightness of mechanical and electrical connections, security of mounting, and general appearance. For detailed maintenance procedures refer to the maintenance section of the manufacturer's manual.

SYNCHROSCOPES

The synchroscope is an instrument which indicates whether two engines are synchronized —that is, whether they are turning the same number of rpm. The instrument consists of a small electric motor which receives electrical energy from the tachometer generators of both engines that are to be synchronized. If both engines—and thus both generators—are running at exactly the same speed, the synchroscope motor does not turn. A double-ended pointer on the dial of the instrument (fig. 20-34) indicates which engine is turning more rapidly than the other.

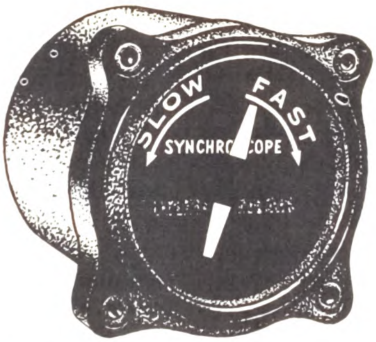


Figure 20-34.—Synchroscope dial.

If one engine is turning more rapidly than the other, its generator will turn the synchroscope motor in one direction. If the speed of the other engine becomes faster than the first, then its generator will gain control. The synchroscope motor will reverse itself and rotate in the opposite direction.

In a synchroscope system it is necessary to designate one engine of the aircraft as the master engine if the synchroscope indications are to have any meaning. The dial readings—with left-hand rotation of the pointer indicating "slow" and right-hand rotation indicating "fast"—would then refer to the operation of the second engine in relation to the speed of the master engine.

For aircraft having more than two engines, additional synchroscopes are used. One engine is selected as the master, and synchroscopes are connected between its tachometer and those of each of the other individual engines. On a complete synchroscope installation of this kind, there will be one less instrument than there are engines, as the master engine is common to all the pairs.

A cutaway view of a synchroscope is shown in figure 20-35. It consists essentially of three parts: a 3-phase stator winding, which is directly connected to a 3-phase generator; a single-phase field coil winding, which is fixed with respect to the stator, and which is connected to a single phase of a second generator; and a rotor, which has two vanes.

The stator consists of the 3-phase winding which is inserted in and insulated from a laminated circular core. The core is separated into two parts, each consisting of a few laminations and separated by spacers. A counterclockwise rotating field is set up in this stator. The speed of rotation of the field is proportional to the generator speed to which it is connected. The field coil is located within the core of the stator. Since it is connected to a single phase of a second generator, the two vanes become oppositely polarized. The polarity of the vanes reverse at a speed directly proportional to the generator speed.

The rotor of the instrument consists of the two vanes, separated by a spacer, and is located on a long slender shaft which extends the length of the instrument. The shaft extends through the center of the single-phase field coil with the vanes located on either side of the coil, and separated by the spacer. The vanes are soldered to the shaft, and are located approximately 180° apart. This permits the vanes to line up with the two sections of the laminated core of the stator.

Assuming, for purposes of illustration, that both generators are in synchronism, at a certain instant one vane will be of N polarity and will line up toward the S pole of the revolving field; the other vane, of S polarity, will be lined up with the N pole of the rotating field. One-half cycle later the polarity of the vanes has reversed, but the rotating field has turned through 180° so that the relative polarities will be the same and the vanes still remain in the same position.

Next, assuming that the single-phase supply generator increases its rpm slightly, the vanes will attain their maximum magnetization before the rotating field has shifted 180° and the vanes will revolve clockwise to line up with the direction of the rotating field; thus, there will be produced a rotation proportional to the difference in speeds and in a direction which will indicate the relative speeds of the two generators. In summary, the 3-phase stator causes a 3-phase field within the stator, while

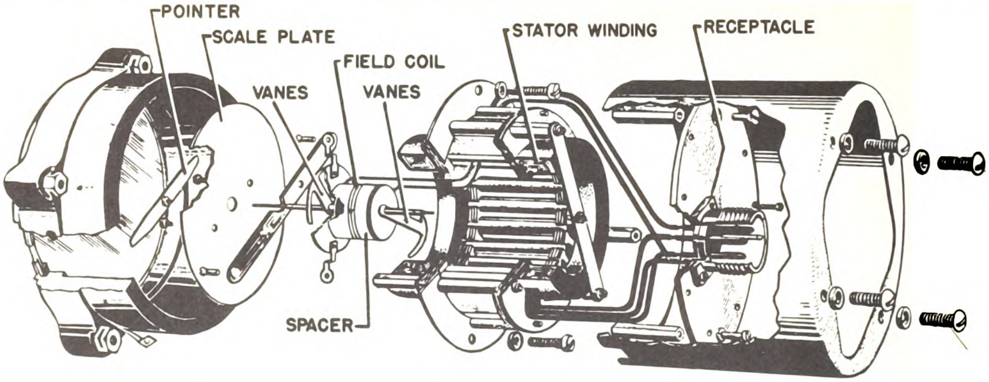


Figure 20-35.—Cutaway view of a synchroscope.

the single-phase coil produces a single-phase field which changes in polarity each half cycle. The vanes rotate at a speed which is the difference between the rotating 3-phase field and the pulsating single-phase field. This movement of the vanes represents the relative speed of the two prime movers (engines) to which the generators are attached. Indication on the scale is obtained by a pointer which is attached to the rotor shaft.

The four-engine synchroscope is a special adaptation of the synchroscope and is used on four-engine aircraft to indicate when the engines are synchronized. It is actually three individual synchroscopes placed in one case.

The rotor of each is connected electrically to the tachometer generator of the engine designated as a master while each stator is connected to one of the other engine tachometers. There are three hands, and each hand indicates the relative speed of the number two, three, or four engine.

GYROSCOPIC INSTRUMENTS

The three basic gyro instruments are the turn-and-bank indicator, the directional gyro, and the gyro horizon. The turn-and-bank indicator utilizes the gyroscopic property of precession and is a semirigidly mounted instrument. The directional gyro is freely mounted and utilizes the gyroscopic property of rigidity in space to establish a reference plane and the gyroscopic property of precession to maintain the spin axis of the gyro in a plane horizontal to the earth's surface. The gyro horizon is freely mounted and utilizes the gyroscopic property of rigidity in space to establish a reference plane and the gyroscopic property of precession to maintain the vertical (spin) axis of the rotor perpendicular to the earth's surface.

GYRO OPERATION

The rotors of gyros must rotate continuously in order for the gyroscopic type instruments to function properly. When these instruments were first used, their gyros were driven by a stream of air. The driving force was obtained from a venturi tube. This tube operated on the principle that pressure decreases as speed increases along a streamlined restriction; it could produce a vacuum only during flight. This system was replaced with the engine-driven vacuum pump, which has since been replaced by electrically driven systems. The principles of operation of gyroscopes, electrically driven or air driven, are discussed in chapter 18 of this course.

Reliability is of utmost importance in aircraft instruments. Since the electrical type gyro is more reliable than the vacuum type, it has found wide application. All gyro instruments now in production or undergoing development are electrically operated.

TURN-AND-BANK INDICATOR

The turn-and-bank indicator is used to indicate the lateral attitude of an aircraft in straight flight and to provide a reference for the proper execution of a coordinated bank and turn. It also indicates the flying of a straight course or the direction and rate of a turn. It was one of the first modern instruments to be used for controlling an aircraft without visual reference to the ground or horizon.

The indicator is a combination of two instruments, a ball and a turn pointer. The ball part of the instrument is actuated by natural forces, while the turn indicator depends on the gyroscopic property of precession for its indications. The gyro of the turn indicator may be driven by vacuum or it may be electrically operated.

Ball

The ball parts of the turn-and-bank indicator (fig. 20-36) consists of a sealed, curved, glass tube containing water-white kerosene and a black agate or common steel ball bearing which is free to move inside the tube. The fluid provides a dampening action and insures smooth and easy movement of the ball. The tube is curved so that when it is held in a horizontal position, the ball has a natural tendency to seek the lowest point, which is the center. A small projection on the left end of the tube contains a bubble of air which allows for expansion of the fluid during changes in temperature. Two strands of safety wire are wound around the glass tube approximately one-half inch apart. These strands of wire fasten the tube to a metal disk or plate in the front of the instrument case. They also serve as reference markers to indicate the correct position of the ball in the tube. The plate to which the tube is fastened and the reference wires are usually painted with a luminous paint.

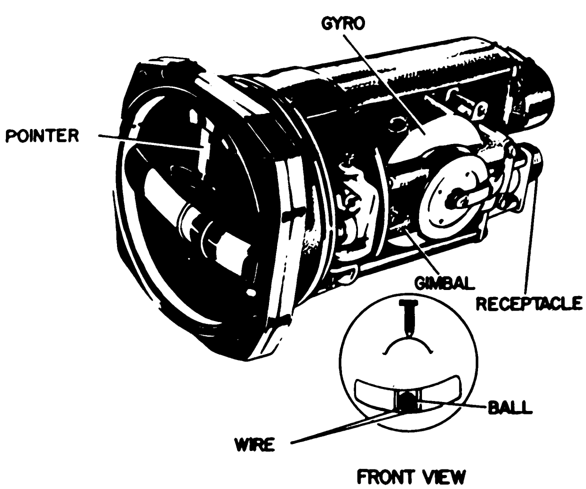


Figure 20-36.—Turn-and-bank indicator, electrically driven.

The natural forces acting on the ball in straight-and-level flight are gravity, which acts toward the center of the earth, and the force exerted by the bottom of the tube, which is always perpendicular to the tangent at the point of contact. It acts from the point where the ball makes contact with the tube through the center of the ball.

The natural forces acting on the ball in a coordinated turn are:

1. Gravity which pulls toward the center of the earth.
2. The force exerted by the bottom of the tube, which remains perpendicular to the tangent at the point of contact.
3. Centrifugal force which acts in the horizontal plane and outward from the center of the turn.

The ball assumes a position between the reference markers when the resultant of centrifugal force and gravity acts directly opposite the bottom of the tube midway between the reference markers. When the forces acting on the ball become unbalanced, the ball moves away from the center of the tube.

In a skid, the rate of turn is too great for the angle of bank, and the excessive centrifugal force causes the ball to move to the outside of the turn. The resultant of centrifugal force and gravity is not opposite the midpoint between the reference markers; consequently, the ball moves in the direction of the force which is the outside of the turn. To correct to coordinated flight calls for increasing the bank or decreasing the rate of turn, or a combination of both.

In a slip, the rate of turn is too slow for the angle of bank, and the resultant of centrifugal force and gravity causes the ball to move forward to the inside of the turn. To correct to coordinated flight requires decreasing the bank or increasing the rate of turn, or a combination of both.

The ball instrument is actually a ''balance'' indicator, because it indicates the relationship between the angle of bank and the rate of turn. It enables the pilot to know when the aircraft has the correct angle of bank for its rate of turn.

Turn Pointer

The turn pointer is actuated by a gyro which may be driven by vacuum or electricity. The gimbal ring encircles the gyro in a horizontal

plane and is pivoted fore and aft in the instrument case, as shown in figure 20-36. This unit is driven electrically and is typical of naval aircraft turn-and-bank indicators.

The major components of the instrument are:

1. A frame assembly that is used as a means of assembling the instrument.
2. A motor assembly consisting basically of the stator, rotor, and motor bearings. The electrical motor serves as the gyro for the turn indicator.
3. A rear plate assembly that is used for mounting the electrical receptacle, pivot assembly, and a choke coil and capacitors for eliminating radio interference.
4. A damping unit that is used to absorb vibrations and prevent excessive oscillations of the needle. The unit consists of a piston and cylinder mechanism, and the amount of damping may be controlled by adjustment screws.
5. An indicating assembly composed of a dial and pointer.
6. The cover assembly.

The gyro is carefully balanced and rotates about the lateral axis of the aircraft in a frame that pivots about the longitudinal axis. When mounted in this way, the gyro responds only to motion around a vertical axis, being unaffected by rolling or pitching.

The turn indicator takes advantage of one of the fundamental principles of gyroscopes known as precession. Precession, as already explained, is a gyroscope's natural reaction at right angles to an applied force. It is visible as resistance of the spinning gyro to a change in direction when a force is applied. As a result, when the aircraft makes a turn, the gyro position remains constant, but the frame in which the gyro is suspended dips to the side opposite the direction of turn. However, because of the design of the linkage between the gyro frame and the pointer, the pointer indicates correctly the direction of turn and the pointer displacement is proportional to the rate of turn of the aircraft. If the pointer remains on center, it indicates that the aircraft is flying straight. If it moves off center, it indicates that the aircraft is turning in the direction of the pointer deflection.

The turn needle is used to indicate the rate (number of degrees per minute) at which the aircraft is turning about its vertical axis.

By use of the turn-and-bank indicator, the pilot may check for coordination and balance in straight flight and in turns. If this instrument is cross checked against the airspeed indicator, the relation between the lateral axis of the aircraft and the horizon (angle of bank) may be determined. For any given airspeed, there is a definite angle of bank necessary to maintain a coordinated turn at a given rate.

DIRECTIONAL GYROS

The directional gyro is an instrument that provides a visual reference point that is an aid in keeping the aircraft on course or that may be used to indicate an accurate turn to a new heading. Also, it is used to maintain alinement when making an instrument landing; aids the pilot and navigator to check each other's calculations; and assists in locating the direction of radio beacon stations. It operates on the gyroscopic principle of rigidity in space.

The rotor of a directional gyro is mounted on a gimbal ring, and is free to turn around the vertical as well as the horizontal axis of the ring while spinning around its own horizontal axis. This, as already explained, is called a "universal" mounting. Some directional gyros have air-driven rotors and others are driven by electrical power. Both operate on the same principles of gyroscopic action.

In current aircraft, the directional information is provided by gyrostabilized compass systems, such as the G-2, C-8, MA-1, and MF-1. These systems were discussed in chapter 18 of this course.

GYRO HORIZON INDICATORS

A pilot determines the attitude his aircraft is flying by referring to the horizon—if and when he can see it. Often enough, however, the horizon is not visible. When it is dark, or when there are obstructions to visibility such as overcast, smoke, or dust, he cannot use the earth's horizon as a reference. When this condition exists, he refers to an instrument called the gyro horizon. This instrument is also called by other names, such as flight indicator, artificial horizon, or attitude indicator. From these instruments the pilot learns the relative position of the aircraft with reference to the earth's horizon.

The horizon indicator gyro rotor revolves with its spin axis in an upright position. This upright position is rigidly maintained as the

aircraft pitches and rolls about the space-rigid gyro. (See fig. 20-37.) A bar on the dial face of the instrument indicates fore-and-aft inclination of the aircraft in either an upward or downward direction. A pointer on the same dial face also shows lateral inclination (or "bank") toward either side. The case of the gyro horizon indicator is rigidly attached to the level of the aircraft; therefore, any movement of the aircraft is synchronously and identically duplicated by the case. The case is free to revolve around the stable gyro because of the mounting of the gyro motor in gimbals. It follows, therefore, that the aircraft itself actually revolves around the rotor and is the complementing factor in establishing the indications of the instrument. Figure 20-38 illustrates this explanation.

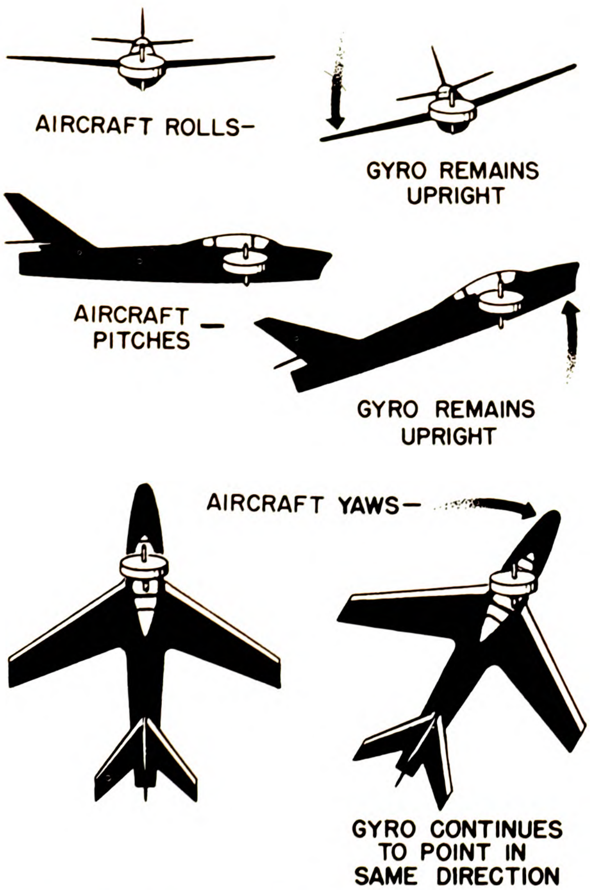


Figure 20-37.—Aircraft reference and gyro stability.

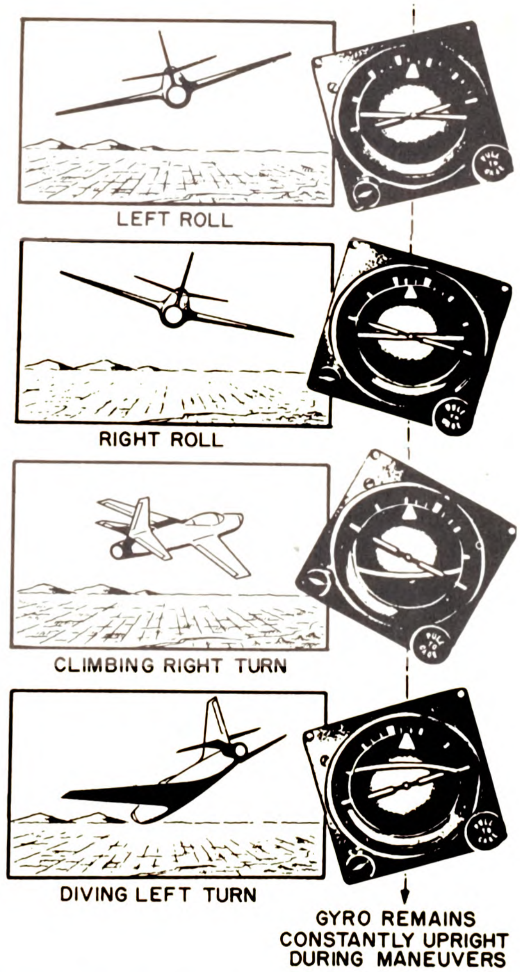


Figure 20-38.—Roll-and-pitch indications.

Various types of gyro horizon indicators are installed on naval aircraft depending on the flight characteristics of the aircraft; however, all indicators furnish the same basic information. The dial configurations are different on many of the instruments. For example, one type is equipped with a scale which indicates in degrees the pitch attitude in a dive and a climb. The gyros of most present-day horizon indicators are electrically driven. Figure 20-39 shows a typical electrically driven gyro horizon indicator.

The electrically driven gyro was designed for fast warmup, high-speed aircraft. These jet aircraft require that the gyro be brought up to the erected position in a very short time

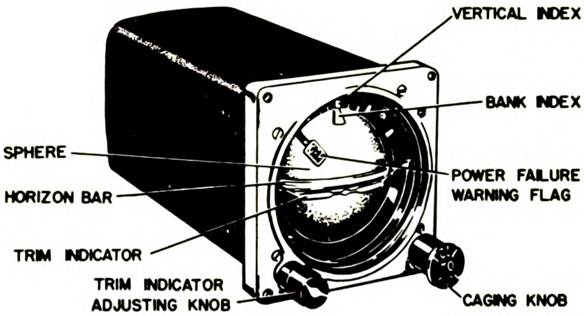


Figure 20-39.—Gyro horizon indicator.

after the power is turned on. The gyro can be erected to the true attitude of the aircraft by a mechanical caging device.

A schematic diagram of a gyro horizon is shown in figure 20-40. Three-phase, 115 volt, 400-cycle power is supplied to the power failure indicator assembly and the gyromotor rotor. The gyro uses about 35 watts of power upon starting and about 10 watts during continuous operation. The phase rotation should be A to B to C with phase A grounded. The power failure indicator is a small warning flag that appears inside the glass cover of the instrument. The warning flag appears when the power to the gyro is off, when the phase rotation is not correct, or when one of the phase lines is open.

Phase rotation can be checked with a special power supply checker. One checker of this type has two lights—one that glows brightly and the other dimly when the phase rotation is correct.

The inside of the glass window is covered with a transparent conductive material, represented by the resistor symbol labeled "heated glass." (See fig. 20-40.) Current from phase A and phase C flows through this material, generating heat that prevents the inside of the glass panel from accumulating condensed water vapor that would prevent the pilot from seeing the indication on the instrument.

VERTICAL GYRO INDICATORS

Another instrument system which uses a gyroscope is the vertical gyro indicator (fig. 20-41). This system is used to indicate the attitude of the aircraft in roll and pitch, exactly as the gyro horizon does. The gyro horizon has a gyroscope inside the cockpit indicator, but the vertical gyro indicator does not. In the vertical gyro indicator, the gyroscope is located at some point remote from the cockpit. Error signals are received from gyro-controlled synchros.

The vertical gyro system shown in figure 20-42 is receiving error signals only in aircraft pitch attitude, but roll axis operates in a similar manner.

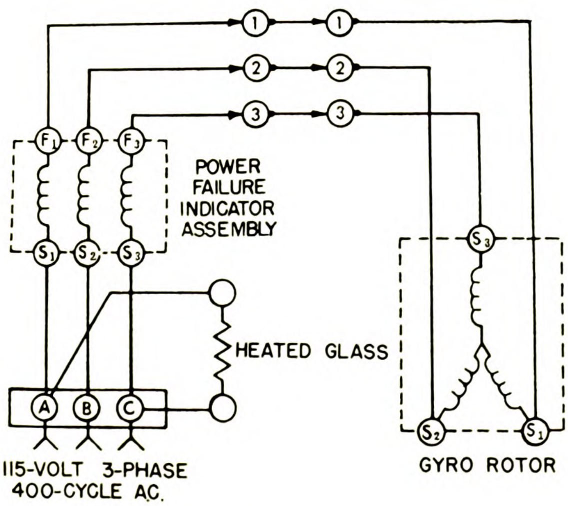


Figure 20-40.—Schematic diagram of a gyro horizon indicator.

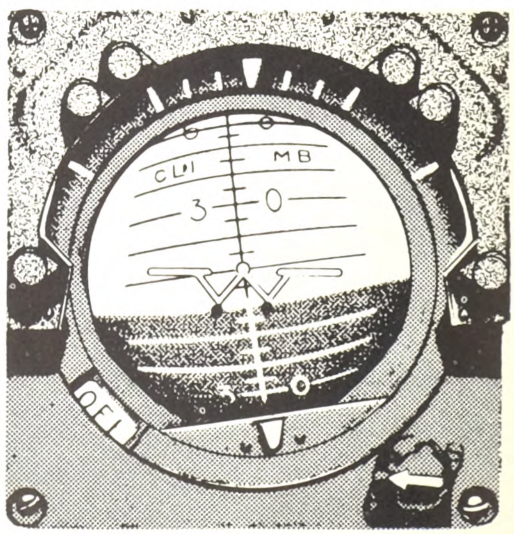


Figure 20-41.—Vertical gyro indicator.

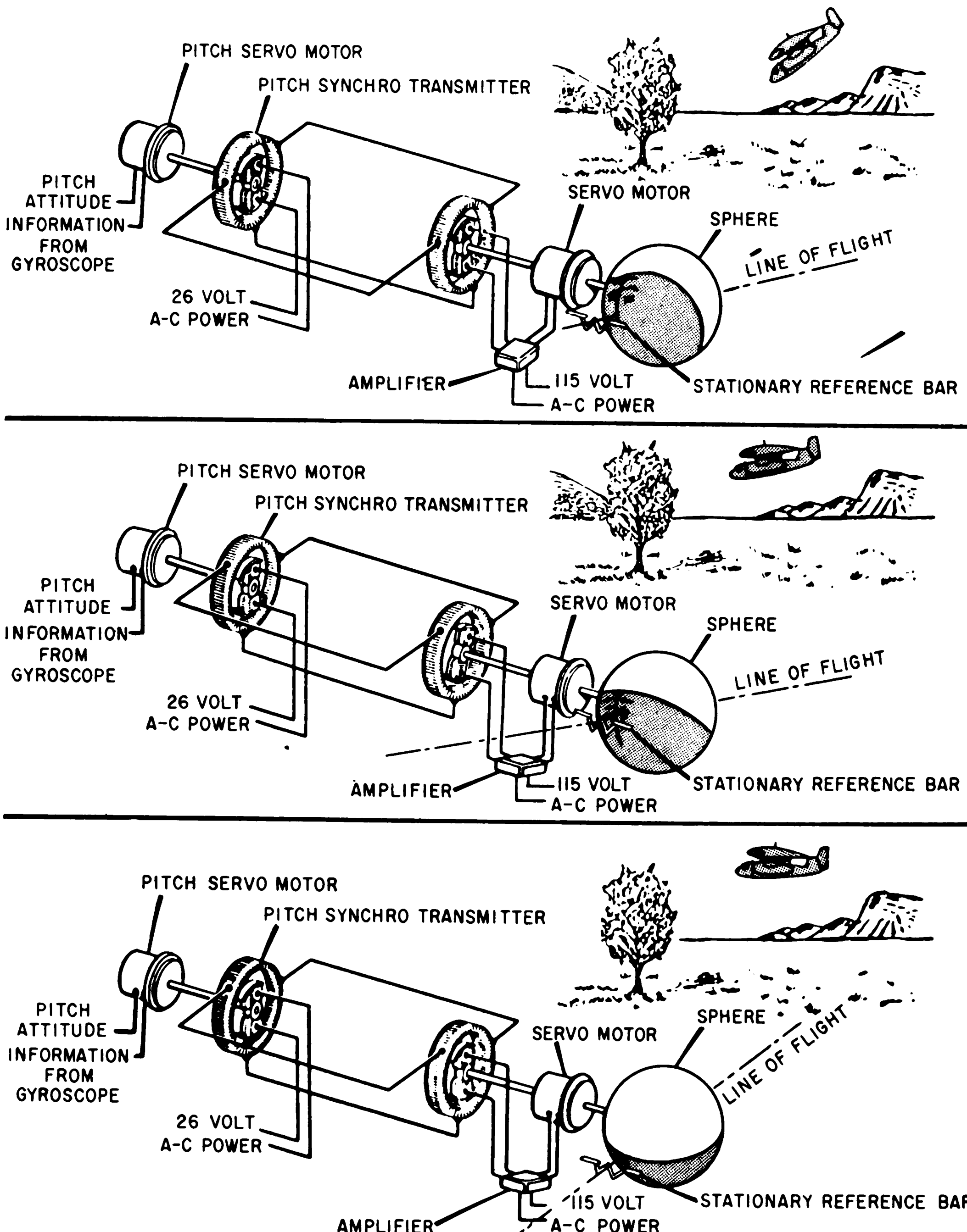
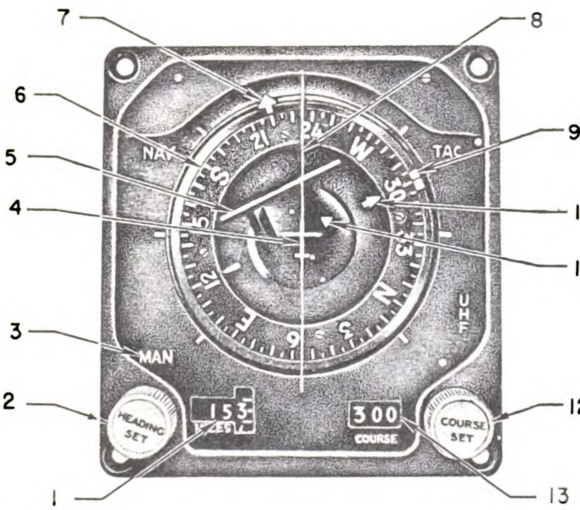


Figure 20-42.—Pitch axis indicating system.

The error signals are received by the pitch servomotor which operates the pitch servo transmitter. The transmitter relays the error signal to a receiver synchro and this signal is sent to the amplifier which controls the indicator servomotor. The indicator servomotor then moves the sphere to indicate the aircraft pitch.

HORIZONTAL SITUATION INDICATOR

The most recent aircraft, such as the F-4B, utilize the horizontal situation indicator to provide the pilot with a visual indication of the navigational situation of the aircraft. The horizontal situation indicator (fig. 20-43) is installed on the pilot's main instrument panel.



1. Distance counter.
2. Heading set knob.
3. Mode light.
4. Aircraft symbol (fixed).
5. Course deviation bar.
6. Compass card.
7. Bearing pointer.
8. Lubber line.
9. Command heading marker.
10. Course pointer.
11. To-from pointer.
12. Course set knob.
13. Course counter.

Figure 20-43.—Horizontal situation indicator.

It provides a visual presentation of the horizontal or plan view of the aircraft with respect to the navigation situation. It also provides an integrated display of navigation data from various sources and presents this data to the pilot in a symbolic-pictorial display for quick and easy assimilation. The center portion of the display contains an azimuth or compass card (6), which displays aircraft magnetic heading when read against the top of the lubber line (8), and against which the bearing pointer (7), course pointer (10), and command heading marker (9) may be read.

The bearing pointer (outer pointer, shown at 210°) provides pictorial bearing information to the ADF station, TACAN station, or the base or target (as computed by the Navigational Computer Set). The course pointer (inside compass card, at 300°) indicates the selected TACAN course (TACAN radial), or aircraft magnetic ground track. The course deviation bar (5) (center segment of this pointer) indicates the aircraft's deviation from the selected TACAN course, as shown pictorially with respect to the stationary miniature aircraft symbol (4), at the center of the display.

A to-from pointer (11) (just above the aircraft symbol) shows whether or not the selected TACAN course leads to the TACAN station. A command heading marker just outside the compass card (shown at 300°) indicates the command magnetic heading and, by its angular displacement from the lubber line, the heading error angle. Both the course pointer and the command heading marker may be set either manually by means of the COURSE SET (12), and HEADING SET (2) knobs, or remotely by external signals to the HSI course command and heading command servos. The selected TACAN course or aircraft magnetic ground track is also indicated on the course counter (13) at the lower right of the display, while a distance counter (1) at the lower left indicates the distance in nautical miles to the TACAN station, or the base or target (as computed by the Navigational Computer Set).

There are four mode-of-operation lights (3) (TAC, UHF, MAN, NAV) shown around the display. These are illuminated internally to indicate the selected operating modes. The unilluminated words remain practically invisible. The instrument is integrally lighted.

The detailed operation of the horizontal situation indicator system, refer to the applicable Maintenance Instructions Manual.

INSTRUMENT TROUBLESHOOTING

Maintaining the many aircraft instruments and their associated equipments calls for a wide variety of skills. It is difficult to place too much emphasis on the importance of checking, inspecting, and maintaining these instruments since the aircraft cannot perform properly unless the instruments are presenting reliabl information.

The accuracy imposed on the instruments used in high-speed aircraft requires assurance that such instruments are giving correct indications. The necessity for preventive maintenance is exemplified by such instruments as percent type tachometers, tailpipe temperature indicators, gyro attitude and control indicators, and fuel quantity and fuel flow systems. The existence of excessive errors in such instrument systems has a direct relation to flight safety and to efficient aircraft performance. It cannot be assumed that borderline instrument errors are acceptable for the successful operation of aircraft. This is of particular importance with high-speed aircraft.

Assurance of correct aircraft instrument indication can be attained only by periodic functional testing. Instrument testing requires time, and advantage must be taken of each inspection check to accomplish instrument operational and functional tests. The AE should become thoroughly acquainted with the operation and use of aircraft instruments and associated maintenance tools and test equipment. Without this knowledge and skill he will not be able to perform the jobs of his rating.

GENERAL INSTRUCTIONS

Cases

Instruments, regardless of type, are encased in one of four different kinds of cases: the one- or two-piece phenolic composition cases, the nonmagnetic all-metal case, or the metallic-shielded case. The cases are made in two sizes to provide the advantages of simplified maintenance and removal which accompany such standardization. Special instruments that contain mechanisms too large for adaptation to the standard case must be provided with specially designed cases.

Ease in mounting the instruments on the panel is attained through the use of a locking device molded into the instrument flange assembly and also through the employment of spring locknuts. The mounting screw locking device may consist of either a split brass locking nut, or fiber, or threaded sleeve inserts.

For connections, nonstructural tubing is attached to the case proper by a standard-thread brass insert molded into the rear of the case.

Markings And Graduation

Numerals and indicating pointers are coated with luminous paint, which is applied only at authorized instrument shops. Markings of various colors are applied to the glass instrument face covers to aid flight personnel in confining operation within the prescribed ranges of the equipment.

The markings usually consist of colored arcs applied to the outer edges of the glass instrument coverings or over the calibration on the dial face. Red is used to indicate ranges that are dangerous or permitted only during emergencies; blue indicates operation permitted under certain specified conditions; green indicates the normal operating range; and yellow indicates caution.

WARNING: An index marking of white paint not over one-sixteenth inch wide by three-sixteenths inch long is placed at the bottom center of all instruments color-marked for operating ranges. This index mark is made at the joint between the glass and the case in order to show whether or not the glass cover moves at any time after the ranges have been marked. The proper markings for the instruments used in aircraft may be obtained from the flight manual on the particular aircraft.

Panels

Instrument panels are usually made from sheet aluminum alloy of sufficient strength to resist flexing. The panel is nonmagnetic and is painted a dull black to eliminate glare and reflection. Some panels are constructed in two layers so that the instrument faces are flush with the rear panel when they are mounted. The front panel is a reflector panel mounted over the rear panel with sufficient clearance to supply indirect lighting effect. The indirect lighting system is not standard for all aircraft; some aircraft are equipped with spotlights, edge lighting, or a combination of these.

Instrument panels are shock-mounted to absorb low-frequency, high-amplitude shocks. Square-plated type absorbers are used in sets of two, each secured to separate brackets. They should be inspected periodically for deterioration; and, if the rubber is found to be cracked, the pair should be replaced.

Among the instrument maintenance duties of the Aviation Electrician are certain inspections, which are conducted at regular intervals. A daily inspection consists of the following items:

1. Check pointers for excessive errors. Some indicators should show existing atmospheric pressure, existing temperatures, and so forth. Others should indicate zero.
2. Instruments should be checked for loose or cracked cover glasses. Vacuum-operated and pitot-static instruments must be replaced if damaged.
3. Instrument lights should be checked for proper operation.
4. Caging and setting knobs should be checked for freedom of movement and correct operation.
5. Any irregularity reported by a pilot must be carefully investigated.

When performing a more detailed inspection (sometimes called an ''intermediate inspection''), the following items should be checked:

1. All the instruments and their dependent units for security of mounting.
2. Instrument cases, lines, and connections for leaks.
3. Dial markings and pointers for dull or marred luminous paint.
4. Operation and limitation markings for correctness and condition.
5. Instrument and electrical bonding for contact and condition of bonding.
6. Shock mountings for condition of rubber and security of attachment.
7. All lines and tubing behind the instrument panel for freedom of motion, and to determine that they are properly clamped or taped to avoid chafing. Check lines and tubing for freedom from moisture, crimps, and so forth.

After the engines have been started, the instrument pointers should be checked for oscillation, and readings should be checked for consistency with engine requirements and speeds. In the case of multiengine aircraft, the instruments for the various engines should be checked against each other, and any inconsistency should be investigated, since it is probably indicative of a faulty engine, component, or instrument.

After careful diagnosis of a particular trouble has been completed, and if the instrument has been determined to be faulty, it should be removed immediately and turned in to the supply activity along with the reasons for its removal. The following precautions should be remembered when removing and installing instruments:

1. They should be carefully handled at all times. Additional damage may result if the instrument is abused.
2. The location of an indicator is not to be changed.
3. Do not force the mounting screws. If the screw is cross-threaded, replace it. Do not draw the screws up too tight against the panel. The case may be distorted sufficiently to affect the operation of the instrument, crack the case, or break off the mounting lugs.
4. Small tools should be used in making hose or tubing connections to the instruments. Excessive pressure or twisting force should not be used to install fittings.
5. Instrument thread compound should be used as directed on threaded connections.

Lubrication

Generally, instruments will require little or no lubrication in the field. The shafts and bearings of instruments are lubricated before assembly and no further lubrication should be required until the instrument is sent to O to R for overhaul. Overhaul operations for aircraft instruments are performed by specially trained personnel only.

INSTRUMENT TESTING

The operation of most aircraft instruments is entirely automatic. Once installed, the units require no further maintenance or servicing other than the performance of routine and periodic inspections. If malfunctioning of a system or an instrument occurs, it is first necessary to localize the source of trouble. A systematic troubleshooting procedure, including the possible service troubles and their remedies, should be developed for each type of instrument. Much of this information may be found in pertinent aeronautical publications and in the Maintenance Instructions Manual for specific aircraft and the Service Instruction Manual for specific instruments.

An instrument reported as functioning improperly, or otherwise suspected of being unserviceable, must first be checked to determine whether the instrument of the installation is at fault. Usually troubles fall into three groups: trouble in the power supply; trouble in the unit; or trouble in the connections to units, either

electrical or mechanical. If the installation is faulty, it can be corrected by line maintenance. If the instrument is the cause of the trouble, in most cases it must be removed and replaced with a serviceable unit. The defective unit should be sent to a qualified instrument overhaul depot for detailed inspection, overhaul, and repair.

Portable Field Test Sets

When making ground tests of electrical instruments, an external power supply should be connected to the aircraft's external connections. The battery should not be used in conducting ground tests of equipment.

Ground testing is performed with portable field test sets such as the VP-2 (used on altimeters, airspeed indicators, etc.) and the TRJ-2 tachometer tester. These and several other tests sets are discussed in chapter 23 of this course. For additional information on operation and servicing of test sets, see the applicable Service Instruction Manual.

Always use a precision voltmeter to check instrument power. Many of the electrical instruments may be checked by using a test indicator to determine whether the trouble lies in the unit or in its electrical connections. For example, Magnesyn indicators may be checked by using a Magnesyn test indicator.

Troubleshooting Chart

The manuals that the AE will use in connection with instrument maintenance contain troubleshooting charts. These charts help the AE to determine what is wrong with an instrument system, and they are designed primarily for the maintenance man. The troubleshooting chart for the particular instrument should be consulted as soon as the nature of the trouble is known since it gives a listing of the common troubles, probable causes, and remedies.

Efficient troubleshooting calls for an orderly, systematic plan of attack and a good understanding of the theory of operation of the equipment. A visual inspection should be made first. This will frequently pinpoint the trouble. When making this inspection, look for discolored or burned wires, discolored or burned terminal boards, corroded switch contacts, broken or frayed wires, loose connector plugs, and loose mechanical assemblies.

Tables 20-1 and 20-2 are typical troubleshooting charts.

INTERCHANGEABILITY OF AIRCRAFT INSTRUMENTS

Extreme care must be exercised in the substitution of aircraft instruments. The Maintenance Instructions Manual for the type aircraft should be checked for the correct type of instrument. This manual usually lists the stock number of the instrument. Another reliable source for the stock and part numbers of instruments for a particular aircraft is Section B, Initial Outfitting List, which is available for every aircraft.

Should the exact replacement for an inoperative instrument not be available, substitution of an interchangeable instrument may prevent undue delay in returning an aircraft to service. Aviation supply items bearing the same stock numbers are operationally interchangeable regardless of the manufacturer or the manufacturer's part number. An instrument which has been assigned a stock number has at least one distinctive feature which has made it advisable to identify it individually. Normally, one instrument will not be substituted for another; however, in an emergency it may be necessary. Before substitution is made, the instrument should be properly identified in the Federal Stock Catalog-Group 66, or some other publication, such as the Maintenance Instructions Manual or other manuals.

EMERGENCY PROTECTIVE TREATMENT

Aircraft instruments that have been submerged in water must, as soon as practicable after immersion, be given treatment to minimize corrosion of parts.

Methods

The instrument case should be opened and the mechanism disassembled to the extent warranted for the particular type of instrument in question. All parts of the mechanism are then flushed thoroughly with a water-displacing, rust-preventive compound. The flushing action may be carried out in a 3- or 4-gallon container, or the instrument may be filled with the protective compound in any convenient manner. The instrument should be shaken vigorously to insure thorough contact of the protective compound with all parts of the mechanism. The instrument is then emptied of liquid so that water will not be allowed to settle

Table 20-1.—Typical troubleshooting chart—airspeed indicator.

Trouble	Probable cause	Remedy
Pointer does not move.	Pitot pressure connection not connected properly to line from pitot tube.	Check tubing and connections for leaks.
	Pitot or static pressure line clogged.	Disconnect pitot and static pressure lines from all instruments. Drain at lowest point of each tube line. Blow through tubing to remove obstructions.
	Defective indicator mechanism.	Replace indicator.
Inaccurate readings.	Leak in tubing from pitot or static pressure fittings.	Check lines to external fittings for leaks.
	Leak in indicator case.	Replace indicator.
	Defective indicator.	Replace indicator.
Pointer does not set on zero when airplane is on ground.	Defective indicator.	Replace indicator.
Pointer oscillates.	Leak in tubing from pitot or static pressure fittings.	Disconnect lines from indicator. Check lines for leaks.
	Leak in indicator case.	Replace indicator.
	Leak in rate of climb indicator or altimeter installations.	Check lines for leaks. If instrument is at fault, replace instrument.
	Moisture in pitot lines.	Drain moisture from lines.

in the bottom of the instrument case. This operation is repeated at least twice. After treatment, the mechanism should be allowed to drain and dry. The instrument, with all parts which have been removed, should be packed carefully and shipped to the overhaul base for immediate repair. The instrument is tagged and the shipment marked externally, "Immersed in water."

The flushing compound may be poured into a container and allowed to settle. The part that does not contain water should be returned to the original storage for further use.

Gyroscopic instruments, such as horizons, directional gyros, turn-and-bank indicators, automatic pilot horizon control units, and automatic pilot directional control units, are partially disassembled prior to protective treatment. In order to insure contact between the flushing compound and the more inaccessible parts of the mechanism during the flushing operation.

In general, instruments should be disassembled to the extent that the various parts of the mechanism will be thoroughly flushed. For treating some manifold pressure gages, it will be necessary to remove the back cover in order for the rust-preventive compound to have free access to the aneroid compartment.

Materials

Many of the components of instrument systems, such as amplifiers, transformers, and capacitors, are given a protective treatment to inhibit the growth of fungus.

This treatment consists of coating the components with a special type fungus-resistant varnish or lacquer. The operation is usually performed by the manufacturer or at O and R. Some maintenance activities may be required to do this job. Since the varnish and lacquer are poisonous, this is a dangerous operation and requires special equipment and specially trained personnel.

Table 20-2.—Typical troubleshooting chart—fuel flow indicating system.

Trouble	Probable cause	Remedy
Sluggish pointer operation.	No power on one rotor.	Check connections.
	Defective indicator.	Replace indicator.
Pointer 180 degrees in error.	No power on one rotor.	Check connections.
Pointer swings in limited arc at top of indicator.	Transmitter ground lead open.	Check connection to pin A of transmitter.
	Reversed power leads.	Interchange power leads
Pointer swings in limited arc at bottom of indicator.	Indicator ground lead open.	Check connection to pin A of indicator.
Pointer swings at side of indicator dial, audible squeal from instrument.	Short or reversed connection between power and stator leads.	Check for short. Interchange power leads.
Pointer swings at side of indicator dial, no audible squeal.	Open stator lead.	Replace lead.
Pointer rotates in reverse direction.	Reversed stator leads.	Interchange stator leads.
Slight movement of pointer.	Defective indicator.	Replace indicator.
	Defective transmitter.	Replace transmitter.
	Clogged or dirty fuel or pressure lines to transmitter.	Clean lines.
Pointer spins.	Power lead reversals, power and stator leads shorted or reversed or making intermittent contact.	Check for continuity and shorts. If wiring is correct, replace indicator.
	Defective indicator.	Replace indicator.
Low fuel indication.	Defective indicator.	Replace indicator
	Trouble in engine fuel regulation system or fuel system.	Refer to fuel system.

REPAIR OF INSTRUMENTS

Only authorized instrument shops are allowed to open instrument cases and make repairs or adjustments. Maintenance that the AE may perform on the small panel instruments, many of which are hermetically sealed, will be limited to flight-line performance checks and replacement of defective units. These sealed units can be repaired only at O and R activities.

CHAPTER 21

AUTOMATIC FLIGHT STABILIZATION SYSTEMS

In the infancy of aviation, the purpose of most flights was merely to remain airborne a short time and return to earth in one piece. However, rapid progress in aircraft development soon made extended flights possible. With these extended ranges of operation came special problems. These problems included the need for precision directional control for air navigation, and a means of reducing pilot fatigue. Aircraft designers soon saw the need for a system of automatic flight controls to relieve the pilot of considerable strain on long flights. They set about designing and building a system which would fly the aircraft, unaided by the pilot, once he had turned it on.

The system which finally evolved would maintain a set heading and attitude even more precisely than the pilot himself. Early systems employed air-driven gyroscopes to detect changes in attitude, and hydraulic pistons attached to the aircraft control cables to make corrective control movements. These early systems were limited to the job of maintaining direction and attitude (straight and level flight), and could do little more. As development continued, extra functions were added to the duties of automatic flight control systems. A system was developed that was also capable of maneuvering an aircraft, in addition to flying it straight and level.

To do this, a small control unit, connected to the automatic flight control system, was installed in the cockpit. By moving this small control (knob or stick), the pilot could cause signals to be sent to the automatic flight control system. The automatic flight control system would in turn cause the aircraft to maneuver in whatever direction the pilot had commanded through his control. Presently, all modern automatic flight control systems are electric and electronic. That is, they employ electrically driven gyros, electronic amplifiers, and electric servomotors to actually move the aircraft control surfaces (rudders, ailerons, and elevators). Though somewhat more complex than the pneumatic-hydraulic system, the electric flight control systems are far superior in performance.

At first examination one might be tempted to observe that automatic flight stabilization equipment is in reality an automatic pilot; but it is more than that. It is an automatic pilot which has been interconnected into the basic control system of the aircraft to a degree not previously attained.

When the automatic flight stabilization system is installed in a helicopter, for example, the pilot flies the helicopter as he has been trained, using the manual flight control, the cyclic stick, the collective stick, and the rudder pedals. The automatic flight control has been combined with the "feel system" so well that the trim characteristics of a well-designed fixed wing aircraft have been attained. To use the equipment, the pilot has only to place it in standby status before takeoff; after lifting the helicopter off, he engages the equipment and may trim it up for forward flight or for hovering by use of the stick trim system. Then by applying forward stick he may increase the speed of the helicopter until the desired flight condition is attained. He may turn by applying coordinated stick and pedal forces as usual. Any flight condition may be trimmed in and flown "hands-off" by use of the stick trim mechanism.

AUTOMATIC PILOT SYSTEM

The original flight control system, which is still being used in some installations, operates on the principle of pilot-controlled servosystems.

In the human body, signals to move us from place to place are originated in the brain as it references outside conditions. These signals are transmitted through the nerves to the muscles, and the body does its required movement by

muscle power. Similarly, most automatic pilots have their component parts divided into three major groups—sensors, amplifiers, and servomotors.

The sensors consist of the units which originate the signals as they are acted upon by outside references. The sensors only sense change in directions and do not have sufficient power to make corrections.

FOLLOWUP SYSTEM

Purpose and Operation of Components

The "brains" for the automatic pilot system are the amplifiers. They receive the weak signals from the sensors, which in this case are synchros. The amplifier has to determine how much and in which direction correction is necessary. The synchro signals are usually in millivolts, but the strength needed is in volts. The amplifier amplifies the millivolt signal to a workable voltage. The value of the millivolt signal produced depends on the amount of displacement of the rotor in respect to the stator from their null positions. The direction of correction needed is determined by the direction of displacement of the rotor from the stator in the synchro. In a typical autopilot the amplifier has at least two stages of voltage amplification, one stage of phase discrimination, and a magnetic amplifier where the power amplification takes place.

The "muscles" of the automatic pilot system are the servomotors. There is one for each control surface (rudder, aileron, and elevator). Servomotors are units which convert automatic pilot electrical signals to mechanical power to control the movements of the control surfaces. The servomotor is basically a 2-phase induction motor geared to a drive shaft.

Summing up the major groups, the sensors send a small signal to the amplifier when a displacement occurs; the amplifier amplifies the millivolt signal to a workable voltage and sends it to the servomotor; the servomotor changes the electrical energy to mechanical energy and moves the control surfaces the proper amount to correct for the displacement of the aircraft.

TYPICAL AUTOMATIC PILOT

A block diagram of the P-1 automatic pilot system is shown in figure 21-1. This is a typical system, and by gaining an understanding of how it operates the AE will have a knowledge that should enable him to understand other systems.

The P-1 system can be broken down into three major channels—the rudder channel, the aileron channel, and the elevator channel. (See fig. 21-1.)

Rudder Control

The rudder channel receives two error signals that determine when and how much the rudder will move. The first signal source is the course signal which is derived from the compass system. As long as the aircraft stays on the magnetic heading that it was on at the time the autopilot was engaged, no signal will develop. However, any deviation from that magnetic heading will cause the compass system to send out a signal to the rudder channel that is directly proportional to the angular displacement of the aircraft from the preset magnetic heading.

Compass systems are used to provide course information to autopilots. For example, the G-2 compass system, when used with the P-1 autopilot, furnishes the autopilot system with the course signal by use of a course synchro transmitter which is located in the master directional indicator.

The course synchro transmitter rotor is attached to the master directional indicator dial through a gear train arrangement and electrical clutch. The rotor is energized with 7 1/2-volt, 400-cycle, single-phase current. The position of the rotor is such that no voltage is induced in the stator when the aircraft is on the course selected by the human pilot. As soon as the aircraft leaves this heading, the compass will detect the change. This causes both the master directional indicator (MDI) dial and the course synchro transmitter rotor to move. This movement causes a voltage to be induced in the stator of the course synchro which is proportional to the distance the aircraft has drifted off course. The phase relationship of the signal is determined by the direction the aircraft drifted off course.

The second error signal received by the rudder channel is the rate signal. The rate signal gives information to the rudder channel any time the aircraft is actually turning about the vertical axis. The turn-and-bank indicator gives this information to the human pilot visually when he is flying the aircraft without the autopilot;

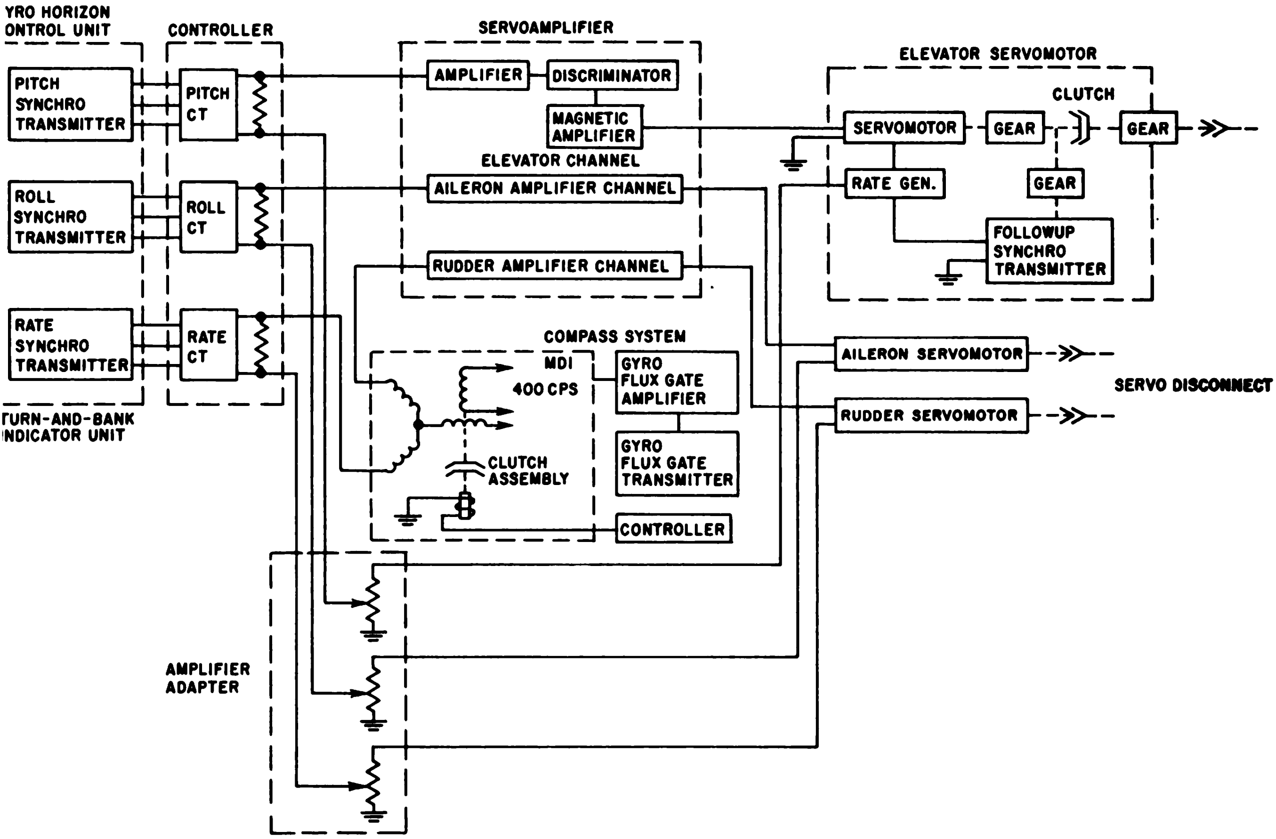


Figure 21-1.—Block diagram of the P-1 autopilot system.

by placing a synchro transmitter in a turn-and-bank indicator, a signal can be developed for autopilot operation.

The rotor of the rate synchro transmitter is attached to the tilt axis of the gyro in the turn-and-bank indicator and the stator is mounted to the instrument case. The rotor of the synchro transmitter is mounted so that there is no rate signal induced to the rudder channel when the aircraft is not moving about its vertical axis. However, if the aircraft moves to the right on the vertical axis, the rotor of the rate synchro transmitter will move in one direction; if the movement of the aircraft is to the left on the vertical axis, the rotor of the synchro will move in the opposite direction. This action causes a signal of one phase relationship (or of opposite phase relationship) to the fixed phase of the servomotor to be produced. As the aircraft turns, the gyro in the turn-and-bank indicator will precess. The amount that the gyro precesses is determined by the rate of turn of the aircraft; the greater the rate of turn, the greater the precession. The precession of the gyro causes the rotor of the synchro transmitter to move from the null position. The output signal from the rate synchro then is proportional to the rate of turn. Figure 21-2 shows the location of the rate synchro transmitter in a turn-and-bank indicator.

The action of the error signals produced by the course synchro transmitter and rate synchro transmitter when the aircraft is forced off course can be illustrated by the following sequence: (See fig. 21-3.)

As the aircraft departs from course, the rate synchro transmitter develops a signal proportional to the rate of turn and the course synchro transmitter develops a signal proportional to displacement. These two signal outputs are connected so that they are additive. The resultant signal is fed to the rudder channel section of the servoamplifier, where the signals are amplified, phase detected, and power

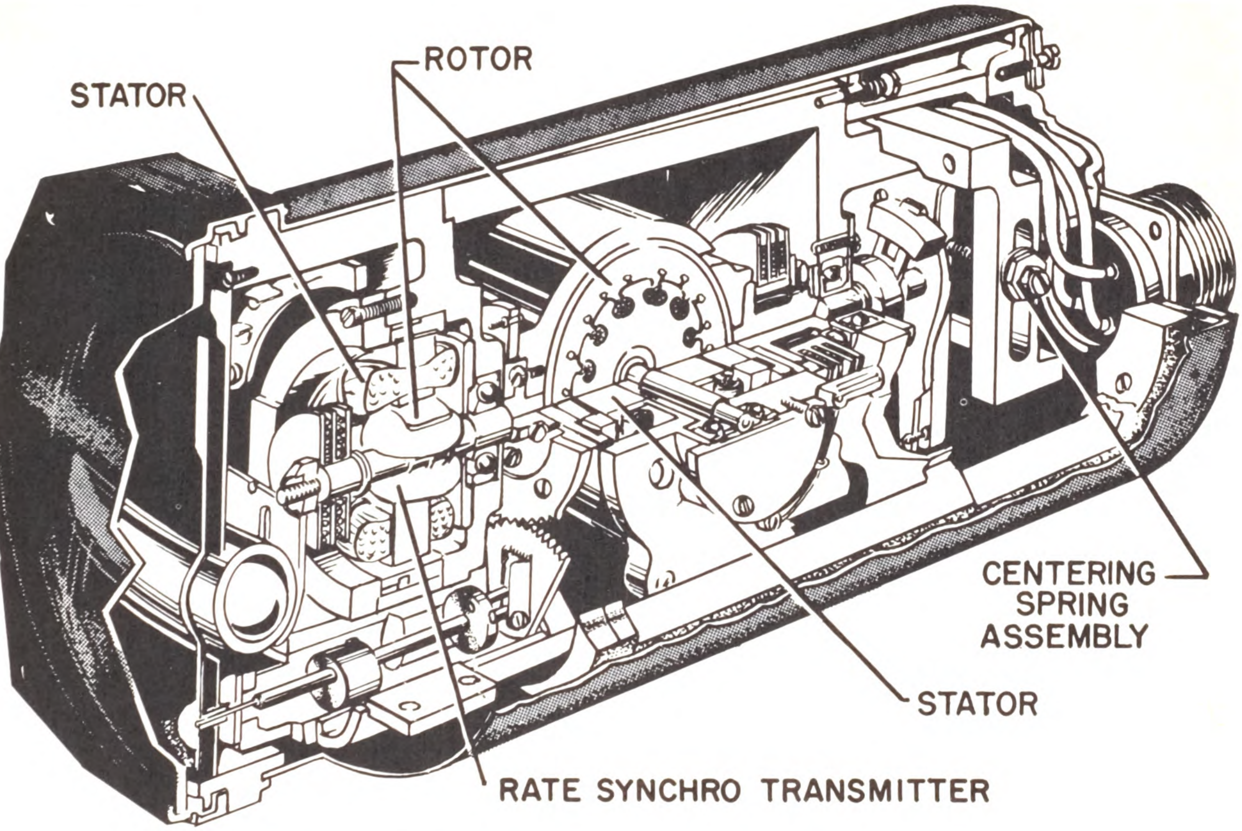


Figure 21-2.—Cutaway view of a turn-and-bank indicator.

amplified by means of a magnetic amplifier. This amplifier signal is fed to the variable phase winding of the servomotor; the fixed phase winding is always excited. The servomotors will run in a manner to cause the rudder to be displaced in such a direction as to stop the turning of the aircraft.

At this time the rudder will stop moving because of a followup signal developed in the servomotor as the rudder was displaced from streamline. The followup signal coming from a synchro transmitter located in the servomotor is always out of phase with the error signal. The purpose of the followup signal is to drive the control surfaces back to streamline. As the aircraft arrives on course, the course signal will reach zero and immediately afterward the control surfaces will be streamline. At this time the followup signal is also zero. The only signal left is a small rate signal which applies reverse rudder to prevent the aircraft from overswinging its heading.

Aileron Control

The aileron channel receives its error signal from a roll synchro transmitter located in the gyro horizon indicator. The rotor of the roll synchro transmitter is connected to the outer gimbal while the stator is connected to the case of the instrument. Any movement of the aircraft about its longitudinal axis will cause the stator of the roll synchro to move around the rotor. This causes a signal to be developed to correct for the error. The signal's magnitude is proportional to the amount of displacement from null, and the phase relationship is dependent on the direction of displacement from null. Figure 21-4 is a cutaway view of a gyro horizon indicator showing the roll synchro and the pitch synchro.

The sequence that occurs in the aileron channel is as follows: (See fig. 21-5.) As the aircraft moves about its longitudinal axis from level flight, the gyro horizon indicator case will move around the gyro. Since the stator of

the roll synchro transmitter is connected to the case of the instrument and the rotor is secured to the gyro, the stator will move about the rotor.

The rotor is energized with 7 1/2-volt, 400-cycle, single-phase current and is nulled at level flight. Any movement from level flight in roll attitude will cause a roll error signal to be developed and sent to the roll channel of the servoamplifier. This signal is sent through two stages of voltage amplification, a phase detection circuit, and a power amplification circuit (magnetic amplifiers). The signal is then sent to the aileron servomotor where the electrical energy is converted to mechanical energy. This mechanical energy moves the aileron control surfaces from streamline to correct for the error.

As the control surfaces move outward, the followup signal sent from the servomotor builds up in opposition to the error signal. When the two signals are equal in magnitude, the servomotor stops moving. Since the control surfaces are displaced from streamline, the aircraft will now start moving back towards level flight with the error signal becoming smaller and the followup signal driving the control surfaces back towards streamline. When the aircraft has returned to level flight in roll attitude, the error signal will again be zero. At the same time the control surfaces will be streamlined and the followup signal will be zero.

Elevator Control

The elevator channel is similar to the aileron circuit. The only difference is that this channel detects errors in pitch attitude of the aircraft. (See fig. 21-6.)

AUTOMATIC PILOT CONTROLLER

The three control channels may also be controlled by the human pilot while in automatic pilot mode by means of a controller unit. (See fig. 21-7.)

Components and Operation

The controller unit consists of three synchro-control transformers. They are the pitch, roll, and rate control transformers. These synchros

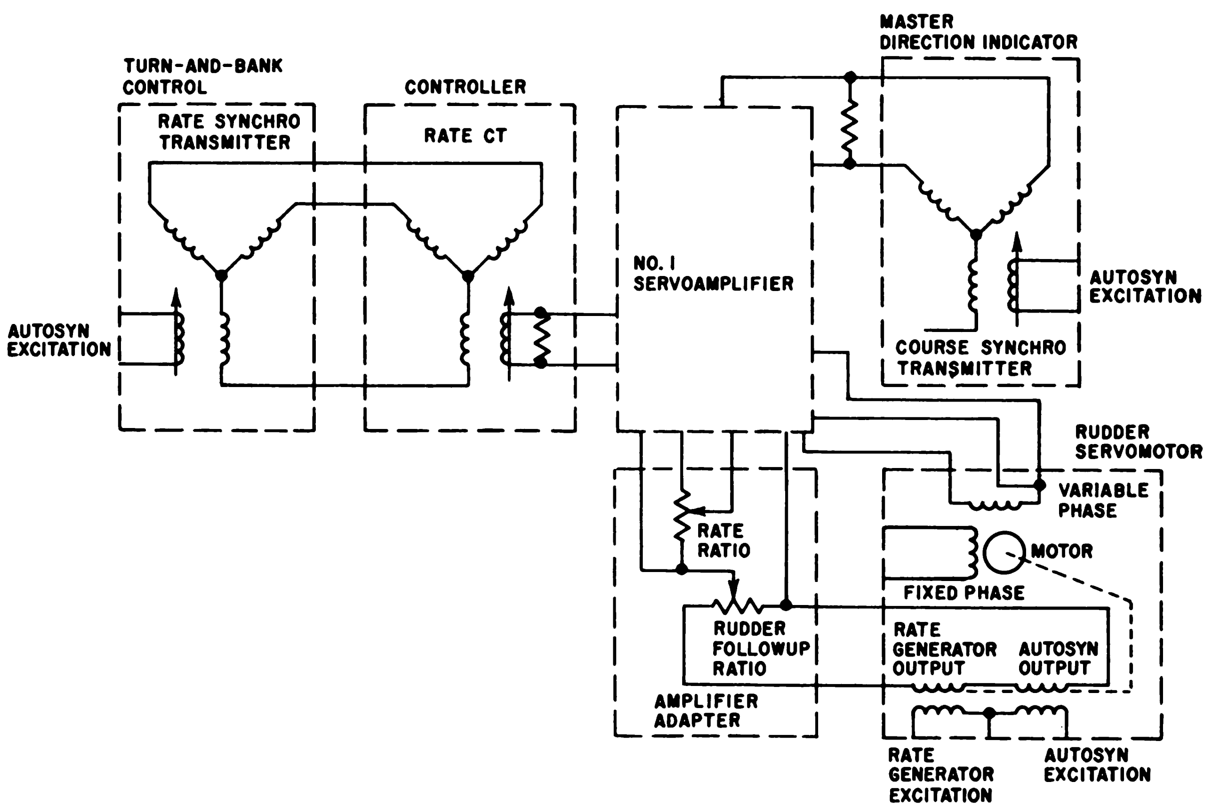


Figure 21-3.—Schematic diagram of the rudder channel.

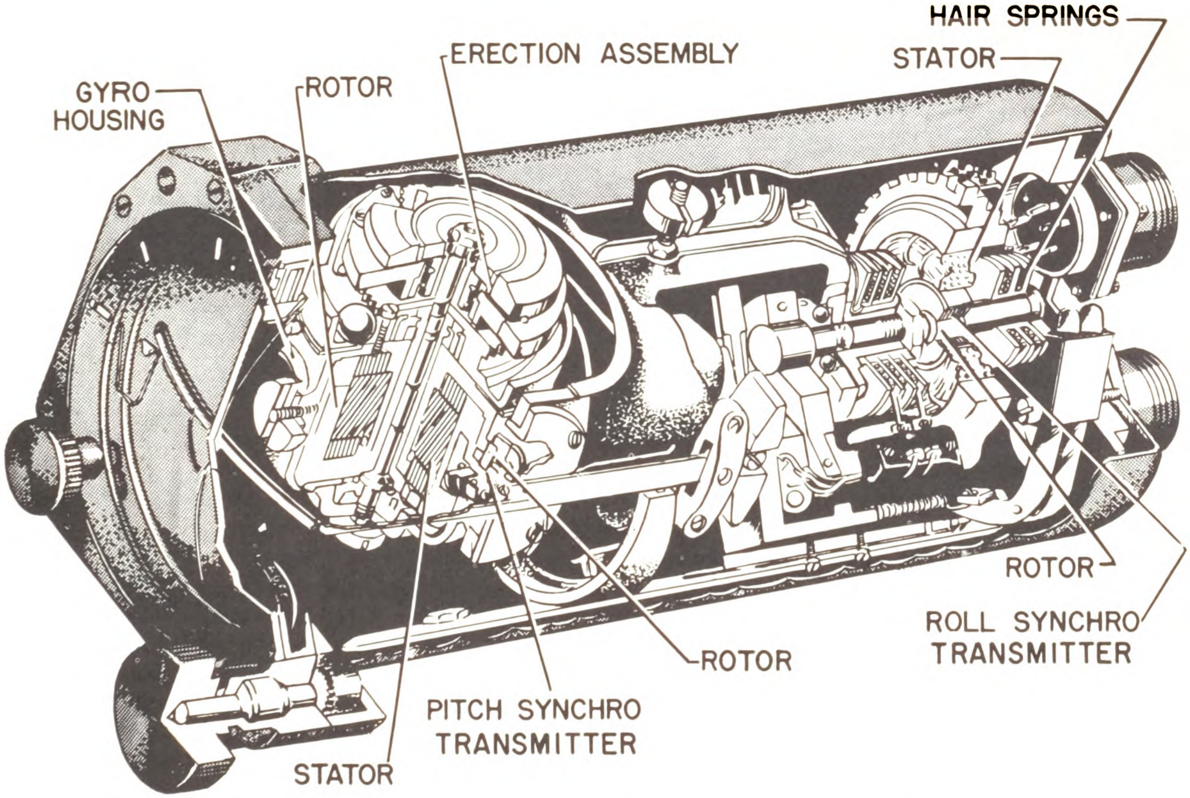


Figure 21-4.—Cutaway view of a gyro horizon indicator.

are identical in construction with the control transformer and synchro transmitter in the master directional indicator. The position of the stators of the control transformers is fixed; the position of each rotor is adjustable. Adjustments in the position of the rotors are made by means of three controls—the turn, the pitch-trim, and the bank-trim controls.

The rotor of the roll control transformer is turned through a mechanical differential when the bank-trim control is turned. It is also turned when the turn control is moved. This is done through the airspeed linkage which is adjustable. When the turn control is moved, the rotor of the control transformer is also turned.

Coordinated Turns

The rotor of the pitch control transformer is also turned through a differential. One side of the rotor is turned by the pitch-trim control. The other side is linked to the movement of the roll and rate control transformers and is moved by the turn control. Provision is made so that, as the turn control is turned to the left or right, the roll and rate control transformers are turned in a corresponding direction. While the rotor of the pitch control transformer may be moved in either direction as a result of adjustments to the pitch-trim control, it is moved in one direction only when the turn control is moved, and that is the direction for the elevators to go up. This introduces enough elevator signal to make a coordinated turn.

A detent is provided at the central position of the turn control. Movement of the control away from the detent, either to the left or right, actuates a switch. The switch is closed when the control is in the detent position and open when the control is moved away from this position. This switch controls the clutch in the master directional indicator through which the rotors of the course control transformer and course synchro transmitter are linked. Therefore, when a turn is commanded by the pilot by the use of the turn control, signals from the course control transformer and course synchro transmitter are disconnected. This prevents their opposing the turning signal. (See fig. 21-1.)

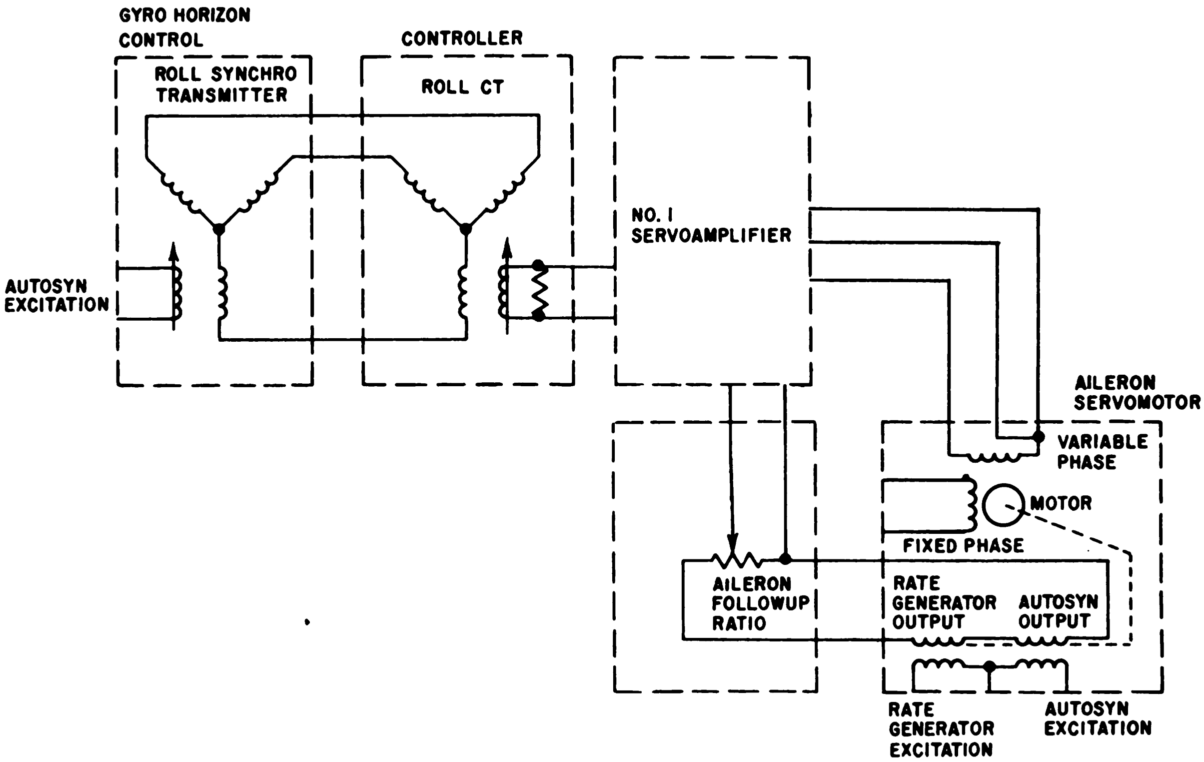


Figure 21-5.—Schematic diagram of the aileron channel.

Checking the P-1 Autopilot

A P-1 autopilot must be adapted to the characteristics of the aircraft in which it is installed. For instance, the flight characteristics of the single engine A-1H aircraft are quite different from those of the multiengine P-2H. The amplifier adapter is the means whereby the automatic pilot may be adjusted to the particular aircraft. In all three channels, direction of servomotor rotation is controlled in the adapter unit. This unit also controls the amount of movement through which the output shafts are moved in response to given signals. The amplifier adapter also serves as a junction point for cables to the servoamplifier and to the servomotors.

The autopilot is engaged and disengaged by a clutch switch. It is held in the ON position by a solenoid. When the solenoid is deenergized, a spring in the switch immediately returns it to the OFF position. A clutch switch and an amplifier adapter are shown in figure 21-8.

Safety Features

The manual caging knob of the gyro horizon control, in addition to controlling the action of the caging mechanism in the gyro horizon, actuates a control switch for the caging relay shown in figure 21-9 (A). This caging relay controls the caging mechanism of the gyro in the gyro flux gate transmitting unit. It is impossible to engage the autopilot if the gyro horizon control is in the caged position. This is a safety feature in the caging relay. If the autopilot is engaged and the pilot happens to cage the gyro horizon control, the autopilot will become disengaged immediately.

An emergency mechanical disconnect (fig. 21-9 (B)) is mounted on each servomotor output shaft. The emergency disconnect allows the pilot to disconnect the servomotor shafts from the control surface pulleys. This would be done any time the pilot could not overpower the autopilot. The emergency disconnects are operated by pulling a lever marked EMERGENCY

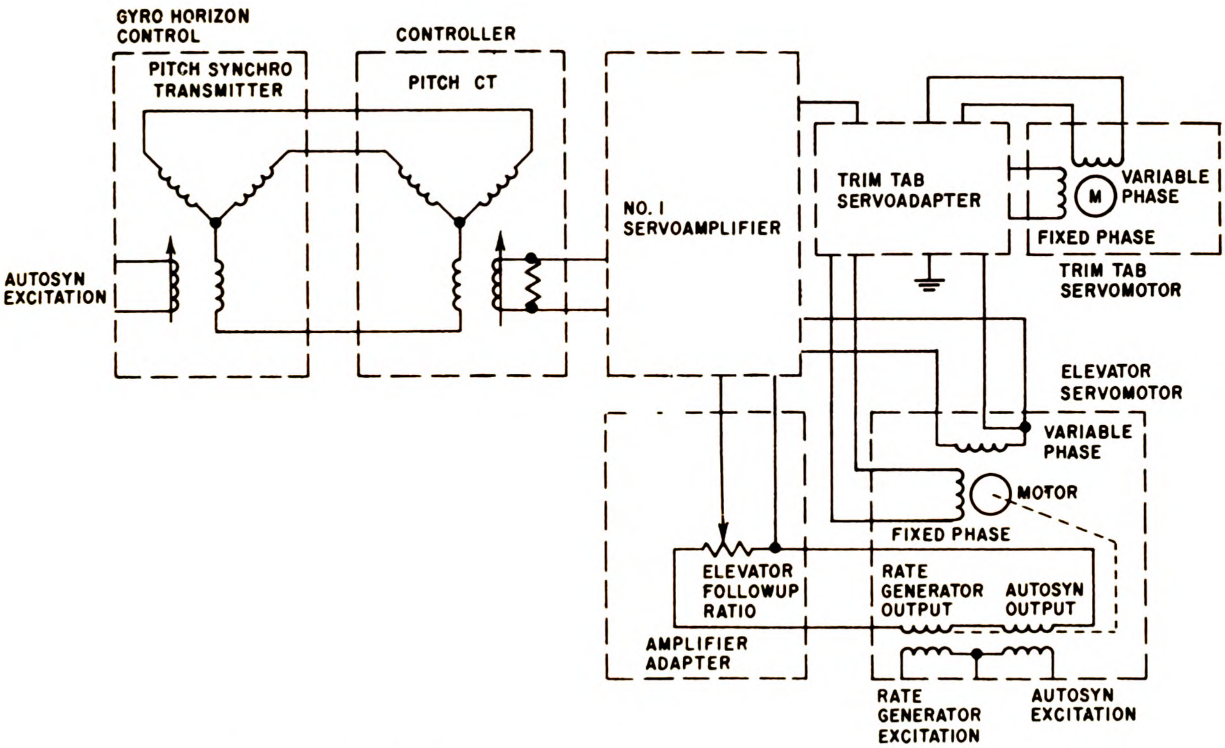


Figure 21-6.—Schematic diagram of the elevator channel.

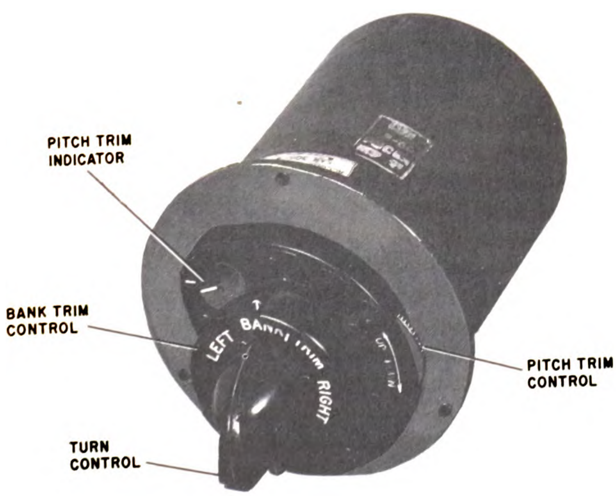


Figure 21-7.—Controller unit.

DISCONNECT. Resetting of the disconnects must be done with the aircraft on the ground.

Figure 21-10 shows a typical servomotor and servoamplifier.

Preflight Check

Preflighting the automatic pilot is very important to assure that every circuit is functioning properly. After the aircraft's main power switch has been ON for at least 2 minutes to allow the gyros to come up to speed, put the automatic pilot power switch to ON. Wait 2 minutes for the amplifier to warm up. Check freedom of controls "hard over to hard over." Then cage and uncage the gyro horizon control to check whether the automatic disconnect is operating.

While holding the control column or stick in the normal flight position, push the clutch switch IN. The automatic pilot is now engaged. Rotate the turn knob to the left; the left rudder pedal should move forward, and the stick should move to the left and slightly aft. Rotate the turn knob to the right; the right rudder pedal should move forward, and the stick should move to the right and slightly aft. Then rotate the pitch-trim knob clockwise (down); the stick should move forward. Rotate the pitch-trim knob counterclockwise (up); the stick should move aft. Rotating the bank-trim knob to the left, the stick should move

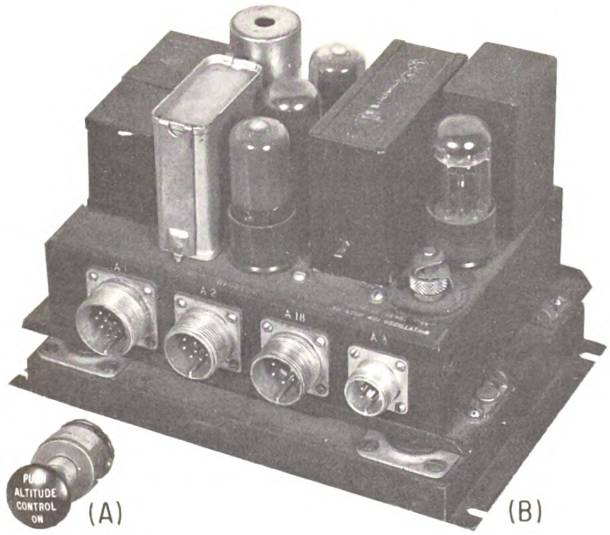


Figure 21-8.—(A) Clutch switch; (B) amplifier adapter.

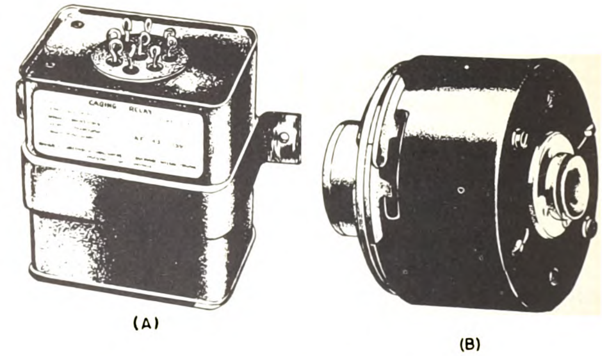


Figure 21-9.—(A) Caging relay; (B) emergency disconnect.

to the left; rotating the bank-trim knob to the right, the stick should move to the right. Then center the bank-trim knob, the turn knob, and the pitch-trim knob.

Disengage the autopilot by pulling out on the clutch switch, and check freedom of the control surfaces by moving the stick and rudder pedals. Then reengage the autopilot and cage the gyro horizon control; the autopilot should disengage again. Turn the power switch OFF.

MAINTENANCE

The maintenance of an autopilot circuit requires a good understanding of how the automatic pilot functions. Usually a proper preflight check will pinpoint the trouble.

Power Supply

For good preventive maintenance make sure that all the cable connectors are tight, the component parts secured properly, and the power supply is of the correct voltage and frequency. The voltage input should be 115-volt, 400-cycle, 3-phase, with ACB phase rotation, and 27.7-volt d.c. Check the wiring diagram for the correct voltage for the particular components. For detailed instructions concerning a particular autopilot system consult the manufacturer's manual.

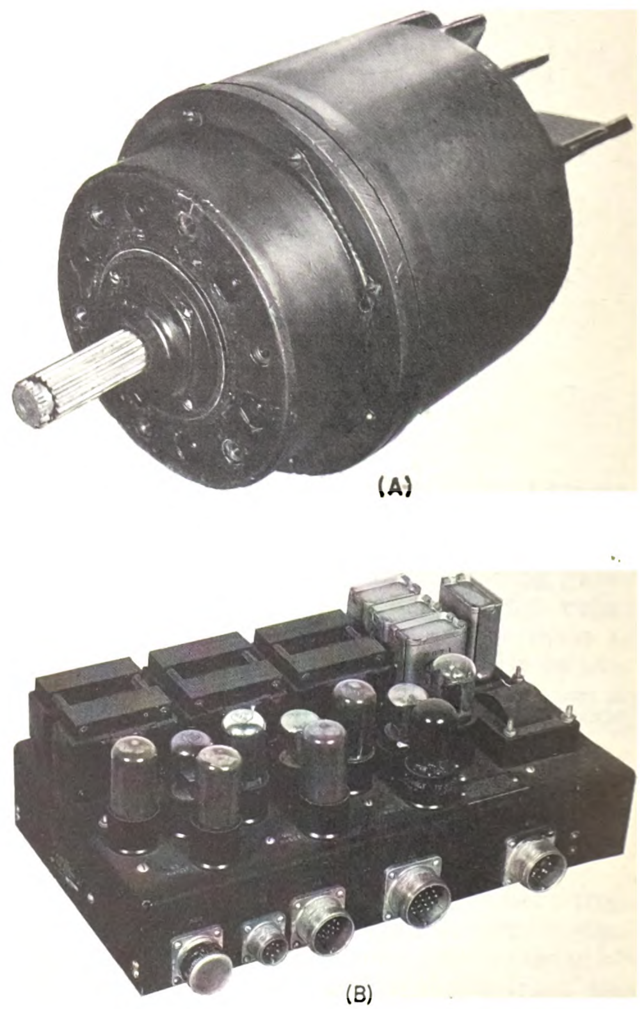


Figure 21-10.—(A) Servomotor; (B) servoamplifier.

ADDITIONAL AUTOPILOTS

The Navy uses many different types of autopilots. The P-1 was used in this chapter to show the functions of a simple autopilot. Later autopilots are not as simplified as the P-1. Some of these are the PB-10A, G-3H, S-5, PB-20, and MH-67. Coverage of these is beyond the scope of this training course.

YAW STABILIZATION SYSTEM

Many high-speed aircraft have tendencies to oscillate about the vertical (yaw) axis. The use of a yaw damper system aids the pilot in stabilizing the aircraft against oscillation about its yaw axis. A block diagram of a yaw damper installation is shown in figure 21-11.

The yaw damper detects any sudden turning of the aircraft and deflects the rudder to oppose the motion. The movement of the rudder may be relatively rapid (several cycles per second) and may be observed at the rudder pedals of any aircraft not using a power-operated rudder. The yaw damper may be engaged and disengaged in flight at the discretion of the pilot. In most installations, in order to free the rudder for takeoff or landing maneuvers, a switch automatically disengages the system when the landing gear is down. In any case, the pilot is able to overpower the unit should it become necessary.

SENSOR AND AMPLIFIER

The basic unit of the system is the yaw damper control assembly (fig. 21-12) which is

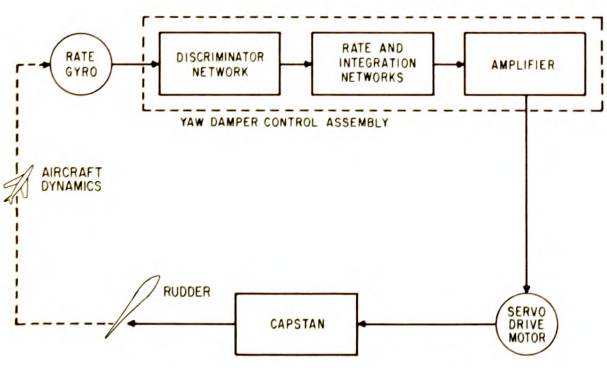


Figure 21-11.—Block diagram of a typical yaw damper system.

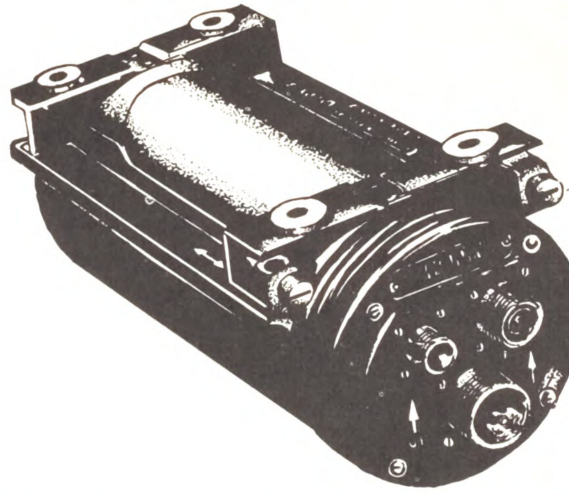


Figure 21-12.—Yaw damper control assembly.

located in the forward part of the aircraft. This unit contains the rate gyroscope which senses changes in aircraft heading, and the electronic circuits (amplifiers, etc.) necessary to transform the information from the rate gyro into signals that can be used to control the rudder servomotor.

OPERATION AS A SERVOSYSTEM

Referring to the block diagram shown in figure 21-11, it can be seen that the yaw damper system is relatively simple compared to a complete autopilot. The rate gyro is mounted in gimbals and is restrained by springs so that its axis of rotation is normally parallel to the roll axis of the aircraft. When the aircraft turns about its yaw axis, either in a coordinated turn or ordinary yaw, the gyro precesses against the springs. The degree of precession is proportional to the rate at which the aircraft is turning. An inductive pickup mounted near the rotor furnishes the signal from the gyro for the rest of the system. When the aircraft is not turning and the gyro is in its neutral position, the voltage induced in the pickup by the gyro is zero. If the aircraft yaws or turns, the gyro is displaced from its neutral position by precessional torques, and a voltage proportional to the rate of turn is induced in the pickup.

The signal will be either in phase or 180° out of phase with the current in that leg of the 3-phase incoming a-c power that is used in the yaw damper control assembly as a reference.

Whether the signal is in phase or out of phase depends on the direction in which the aircraft is turning or yawing. The signal from the pickup is compared with the reference phase in the discriminator network, which produces a d-c output signal. This signal's voltage is proportional to the a-c signal voltage and its polarity is determined by the phase difference. Note that this phase difference is not proportional to the rate of turn. It is either 0° or 180°, depending only on the direction of turn. Signal amplitude is proportional to the rate of turn.

The yaw signal, now in the form of a d-c voltage varying as the aircraft turns is next passed through rate and integration networks. The purpose of the rate network is to "quicken" the system; that is, to provide a phase lead in the slowly varying d-c signal that is applied to the servoamplifiers. This lead will compensate for the phase lag introduced by the servo drive and rudder. At the same time, the integration network shapes the frequency response curve of the system to keep the range of operation within the stable portion of the aircraft's control characteristics. The last section of the yaw damper assembly consists of a two-stage amplifier. The first stage amplifies the signal from the rate network an amount required to give efficient yaw damping and, at the same time, stable operation. The second stage furnishes the power required to actuate one of the two magnetic power clutches in the servo drive motor located in the vertical stabilizer. The polarity of the control signal from the control assembly determines which clutch is engaged.

The servo drive motor positions the rudder, in response to the control signals from the control assembly, through a clutch and drum assembly. The clutch is an adjustable mechanical type and is incorporated in the drum unit to permit manual override of the system in the event of an emergency. It also limits the torque applied to the control surface to the value at which the clutch has been adjusted to slip.

It should be pointed out that the rate network will not respond to steady signals from the rate gyro such as would be produced if the aircraft were turning at a constant rate for a period of time. The damper is designed in this manner so that the pilot does not have to overpower the servo to turn the aircraft. While the rate network does remove the steady state component of the signal from the rate gyro, it still passes transients due to yaw, and the yaw damper system is still operative in the turn.

It has been found necessary to stabilize some aircraft in the pitch axis as well as the yaw axis in order to prevent oscillations of the aircraft. This type of stabilization system is similar to the yaw damper system just discussed, in that it uses gyroscopes to create signals indicative of the pitch movements of the aircraft.

Two signals are required in this system. One indicates the rate of movement in yaw and the other indicates the rate of movement in pitch.

In such a stabilization system two rate gyro units are used. One has the sensitive axis parallel to the yaw axis of the aircraft and the other has the sensitive axis parallel to the pitch axis of the aircraft.

In some stabilization systems synchro accelerometers are utilized to detect displacement of the aircraft about its yaw axis. A voltage is developed within the accelerometers which is proportional to the amount of aircraft displacement. The signal is fed into the rudder channel of the servoamplifier where it is amplified and directed to the rudder servo drive motor.

MAINTENANCE AND TESTING

Maintenance and testing of a yaw stabilization system is very similar to that necessary for an autopilot system. The operation of the system depends on sensing by a rate gyroscope or accelerometer, and amplification of the resulting voltage output by electronic amplifiers. Therefore, testing and preventive maintenance consist largely of voltage checks and specific settings which can be found in the operation and maintenance manuals. The stabilization system just discussed should give a working understanding of any stabilization system which the AE may be required to maintain. For complete operating details and servicing instructions, refer to the Operation and Service Instruction Manual on the system. Manuals of this nature are listed in the Navy Stock List of Forms and Publications, Section VIII, Part C, NavSandA Publication 2002.

AUTOMATIC FLIGHT CONTROL SYSTEM

The development of jet engines, greater speed ranges, and higher control forces has required the use of boost or full power surface

control systems. Numerous aerodynamic and control system changes have been made to obtain specified performance characteristics. A newer version of an automatic flight control system (AFCS) is being incorporated into current aircraft. A block diagram of the AFCS as employed on the A-4E is discussed briefly in this chapter. (See fig. 21-13.)

The AFCS operates the rudder, the elevators, the horizontal stabilizer, and the ailerons. Prior to engagement, the AFCS is synchronized with the flight control surfaces to prevent sudden or violent maneuvers upon engagement. The system permits manual flight control with disengagement.

The AFCS is a servomechanism which senses flight data, converts the data into electrical signals, operates hydraulic valves to move flight control surfaces, and then senses the amount of control surface movement to reduce the input

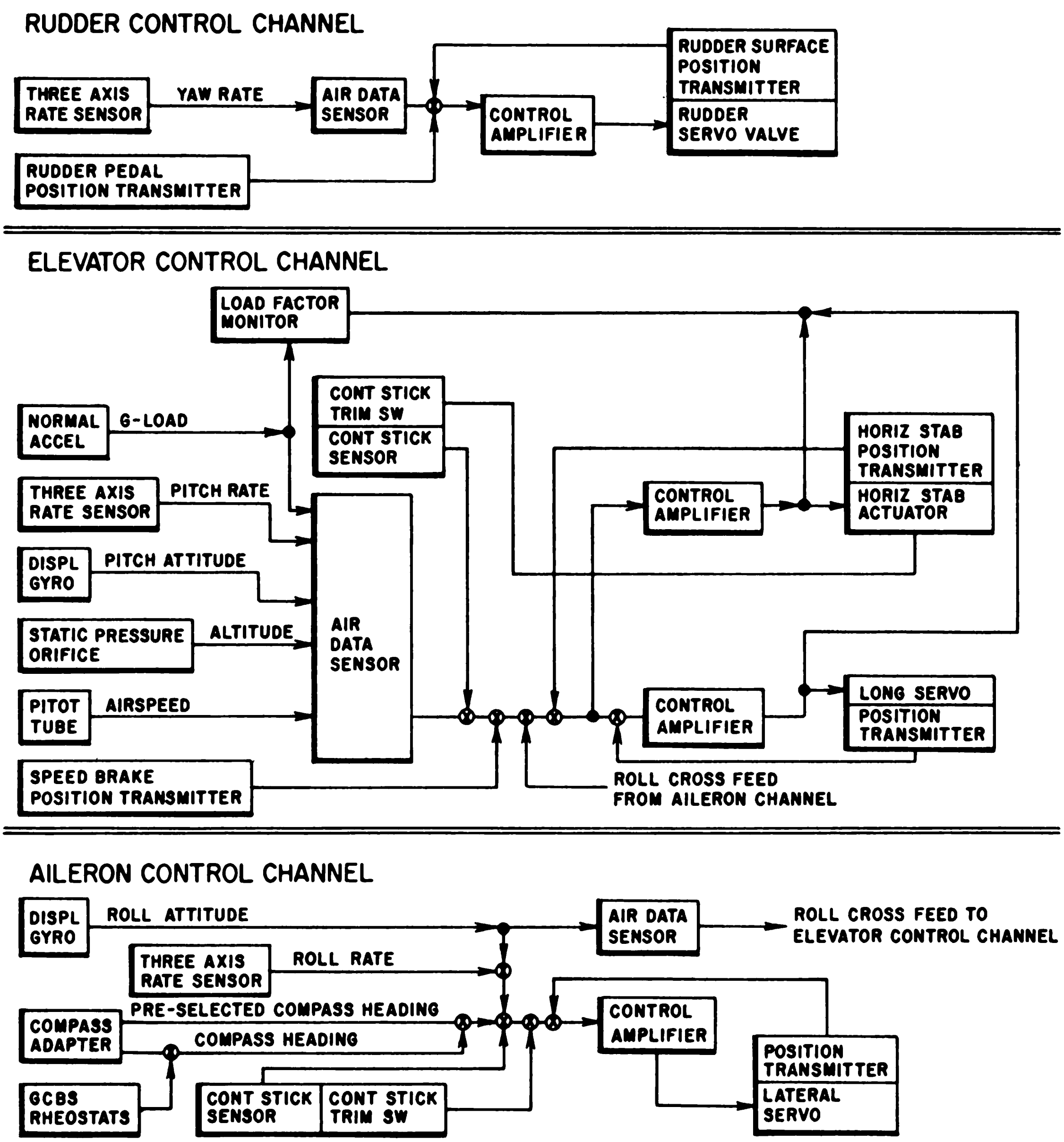


Figure 21-13.—Block diagram of an automatic flight control system.

signal and prevent overcontrol. The system controls flight attitude around the three main axes: yaw, pitch, and roll.

The AFCS consists of the interlock and control circuits and the rudder, elevator, and aileron control channels. The interlock circuit permits engagement of the system. The control circuits place the system in the different modes of operation. The rudder control channel operates the rudder; the elevator control channel operates the elevators and the horizontal stabilizer; and the aileron control channel operates the ailerons.

For detailed information on the theory of operation and applications of typical automatic flight control systems, refer to chapter 10, Aviation Electrician's Mate 1 & C, NavPers 10349-A.

CHAPTER 22

HANDTOOLS FOR THE AVIATION ELECTRICIAN'S MATE

One of the primary duties of the AE is to become proficient with the tools of his trade. This chapter discusses the specific tools which are used by the AE. A good reference source for the use of the more common handtools can be found in Basic Handtools, NavPers 10085-A, and Airman, NavPers 10307-B.

IMPORTANCE OF PROPER TOOLS

Skill in the proper use of handtools is obtained only with experience. However, a valuable store of background information on proper procedures, and on the correct application of tools, may be obtained from a study of various types of tools, their care, and their uses.

An individual's proficiency in using and caring for tools is readily demonstrated in the performance of his duties. The correct selection of tools for the job, the safety precautions observed, and the manner in which the AE conducts himself give a clear indication of his abilities. Remember that a handtool is only as good as the user. Always use the right tool for the job. If in doubt, do not hesitate to consult a senior petty officer. The aircraft costs millions of dollars, and the lives of its crew are not replaceable.

ISSUANCE OF TOOLS

The issuance of tools is controlled at the squadron or activity level on the basis of allowance lists (QG series). The distribution of handtools within the squadron or activity is determined by the type and function of the squadron or activity. The Bureau of Naval Weapons publishes an allowance list of Consumable General Support Equipment for All Types, Classes, and Models of Aircraft (includes standard handtools), NavWeps 00-35QG-016. The purpose of this allowance list is to indicate authorized allowance of consumable general support equipment for the various classes of maintenance of assigned aircraft.

CUSTODIAL RESPONSIBILITY

Most handtools are not feasibly repairable. Due to this fact and their original low cost (compared to shop tools), they are classed as consumable. However, the activity must pay for replacements. Therefore, it is the duty of each individual to help eliminate the need for replacements. One method of accomplishing this is to place an inventory of tools in each toolbox so that upon completion of a job it can be ascertained that all of the tools are accounted for. A tool that has been lost represents a waste of funds; in addition, it is a definite liability. If it has been left loose in an aircraft, it can become a dangerous missile when the aircraft is launched or when the aircraft is performing violent maneuvers.

NAVWEPS 00-35QG-016 SECTION G

As previously indicated, this allowance list is used to indicate the allowance of consumable general support equipment (including standard handtools) for the maintenance of assigned aircraft. All items are listed alphabetically by cognizance symbol and in federal stock number sequence, except for R and V cognizance materials which are listed in Technical Supply Management Code sequence and by FSN within each TSMC.

A copy of NavWeps 00-35QG-016 should be available to each shop for the ordering of tools. Instructions for the use of the allowance list may be found in an introductory section at the front of the publication. An alphabetical listing

of tools is contained in the back of the publication.

The allowance list is divided into 16 columns, numbered 1 through 16. Columns 1 through 4 furnish identification and accountability data. Column 5 indicates whether the item is authorized as organizational property or is to be made available on a subcustody basis. Columns 6 through 16 indicate the authorized allowance based on the maintenance level and the number of aircraft supported.

AVIATION ELECTRICIAN MATE'S TOOLBOX

One of the first steps taken when a new man reports for duty to the electric shop of a squadron or activity is issuing him a complete toolbox. The toolbox should contain all of the low cost, high usage handtools that will enable him to perform the tasks assigned.

USE AND CARE OF TOOLS

There are many instructions and manuals in print, pointing out the right and wrong way to use handtools. These will not be repeated here. However, some advice is given concerning new uses and safe usage of some of the handtools most common to the AE.

Pliers

The diagonal pliers (fig. 22-1 (B)) have been modified by adding potting compound to the jaws. This prevents loss of small pieces of wire into the equipment when cutting wire. The potting compound also allows the electrician to cut the wire without holding onto the piece being cut away. Figure 22-1 (A) shows the diagonals before being modified. These diagonals are available in normal supply; but if the AE does not have a pair, he can modify his own by adding potting compound. Before applying the potting compound, clean the diagonals with solvent. Then secure the handles with a rubberband, as shown in figure 22-1 (C), and apply the compound. Allow 24 hours for the compound to dry. The jaws may be separated by slicing them apart with a single-edge razor.

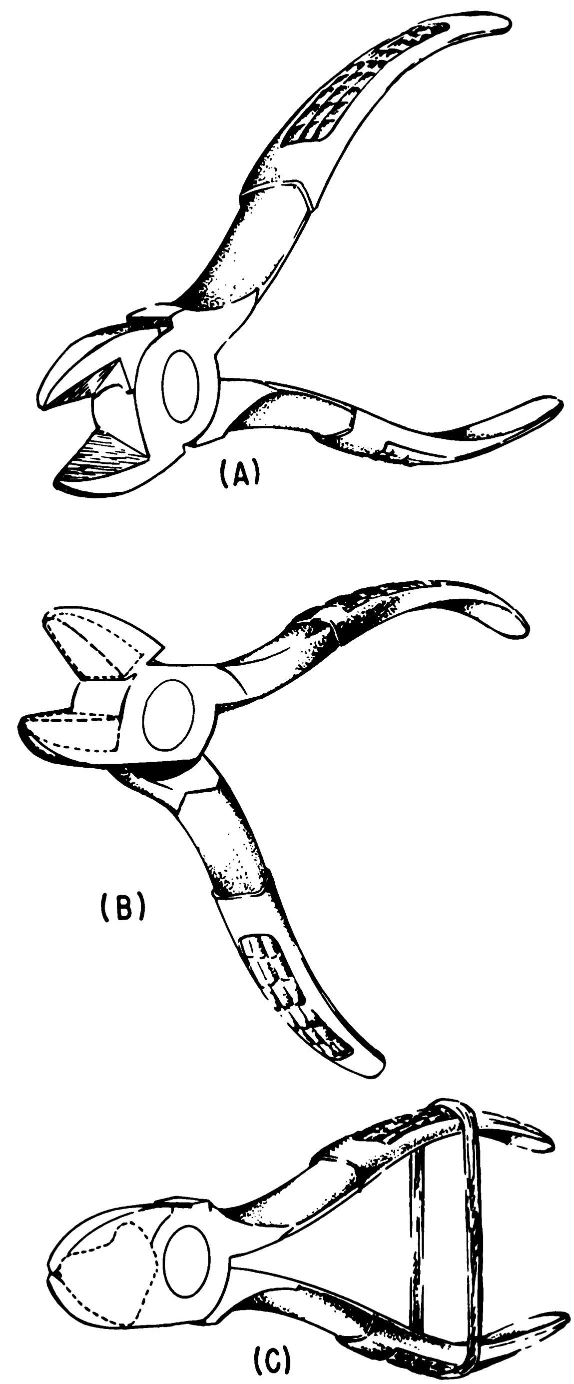


Figure 22-1.—Diagonal pliers. (A) Without compound; (B) with compound; (C) applying compound.

Burnishing Tool

Many relays have been damaged or ruined by the use of sandpaper or emery cloth to clean

the contact points. Use of these abrasives causes bending of the contacts, and attempts to straighten them with long-nosed pliers causes further damage, eventually requiring replacement of the relays. This can be avoided by using a burnishing tool to clean dirty contact points.

Figure 22-2 illustrates a burnishing tool being used on a relay.

Two common types of burnishing tools are stocked in supply activities and may be obtained through normal supply channels. These two common burnishing tools are 2 33/64 inches and 5 inches in length.

Be sure to clean the tool thoroughly with alcohol and do not touch the tool surface prior to use.

Burned and pitted contacts cannot be repaired by burnishing. Relays having trouble this serious should be replaced.

Point Bender

Another handy tool that is often found in an AE's toolbox is a point bender. The point bender (fig. 22-3) is used to straighten bent relay contacts. Bent relay contacts should never be straightened with long-nosed pliers. Such an attempt often causes further damage, with the result that the entire relay must be replaced.

Brush Spring Compressor

The problem of inserting and removing generator brush springs can be solved by the use of a brush spring compressor. This tool is fabricated locally from 1/8-inch steel welding rod. Different versions of the tool will make it useful in removing and installing brushes of generators, simply by bending the rod to fit the particular brush spring arrangement. The brush spring compressor shown in figure 22-4 is designed for the brush springs on an NC-5 power unit.

STOWAGE AND HANDLING

A toolbox will often reflect the personal habits of its owner; that is, if he is sloppy, his tools also are often in need of care; and if he is neat, his tools and toolbox are neat and well cared for.

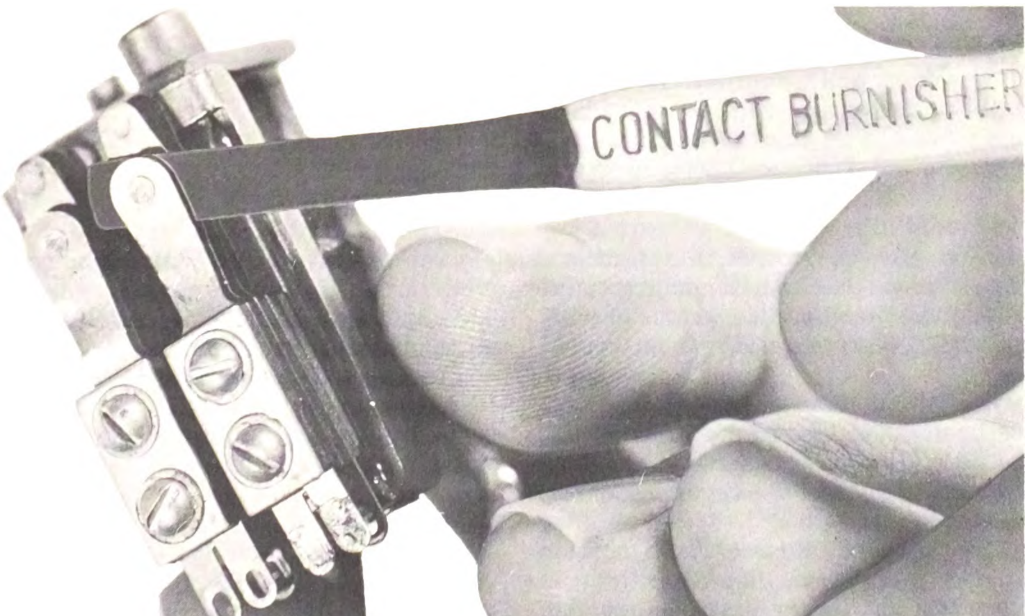


Figure 22-2.—Burnishing tool.

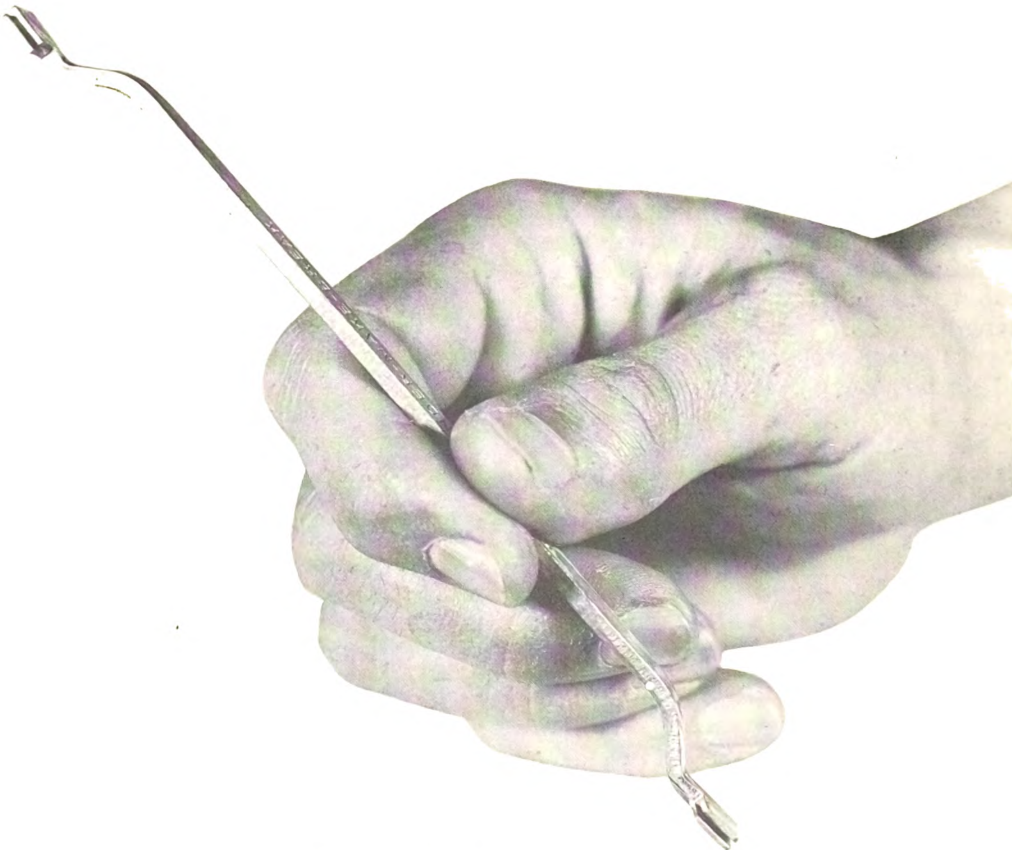


Figure 22-3.—Point bender.

The tools should be stowed in a neat and orderly manner in the toolbox, according to the electrician's need. The ones that are used most frequently should be stowed in the most accessible place.

After each job (if time permits), all tools which have been used should be cleaned and checked. If this is not possible after each job, it should be accomplished before securing for the day.

A tool should never be thrown into a toolbox, but should be placed with the same care that is given to electrical and instrument accessories.

INVENTORY REQUIREMENTS AND REORDERING

After each inventory of the toolbox, the electrician should make a note of worn or damaged tools to aid in reordering.

The senior petty officer in the shop may ask from time to time for an inventory of tools. This spot inventory is a valuable aid to him when he is planning his future needs.

Tools should be reordered as they are needed. It is unwise to wait until the number of tools needed is too large, as it is easier for the supply department to fill a small order rather than a large one.

SHOP TOOLS

Due to the availability of common handtools from an electrician's toolbox, shop tools are usually considered to be only the larger, low usage and special handtools. However, shop tools also include any handtools required to perform more extensive maintenance than can be accomplished from a toolbox. The shop tools are determined by the size and type of the activity and

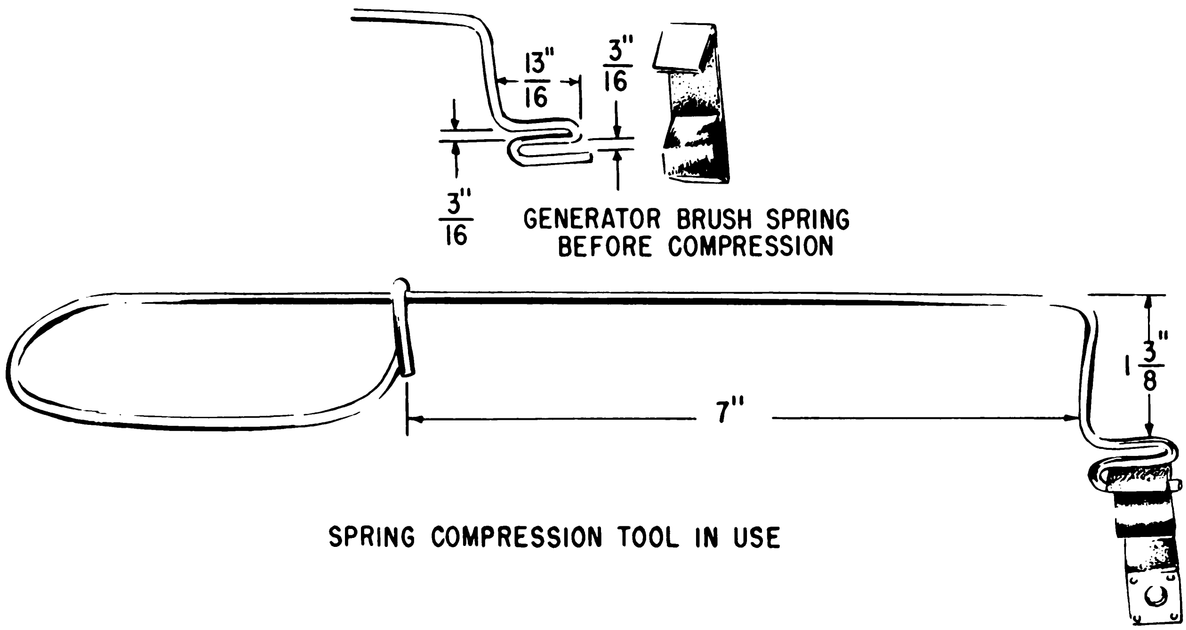


Figure 22-4.—Brush spring compressor.

by the allowance set forth in applicable allowance lists.

TYPICAL TOOLS

This course does not lend itself to complete coverage of the typical tools which may be found in the electric shop. However, a brief discussion of a tool which is relatively new to the AE is presented. This is followed by a discussion of some tools which are typical of those requiring special handling or special precautions.

Taper Pin Insertion and Removal Tool

An innovation in electrical distribution systems is the taper pin electrical connector for aircraft. The taper pin works on the principle of driving a taper wedge into a tapered hole and depending on friction to retain the pin in the hole. The taper pin connector makes an excellent electrical and mechanical connection because of the high metal-to-metal contact pressure developed during the driving action of the insertion tool. Taper pins permit circuit changes to be quickly and easily performed without a soldering iron. Qualification tests show that vibration and corrosion, over a period of time, improve the electrical continuity and increase the mechanical pull-out force required to remove a taper pin. Another advantage of taper pins is the accessibility of test points for voltage and circuit continuity checks.

A special tool, shown in figure 22-5, is used to properly insert the taper pin into the terminal block socket. The insertion tool has a calibrated driving spring, a calibrated pull-test spring, a taper pin captive key, and a taper pin removal feature.

The driving spring adjusts to apply the proper driving impact to the pin. The pull-test spring adjusts to apply the correct pull force on the pin to check for proper pin insertion. The captive key insures that each taper pin has a 100 percent pull test before the tool is disengaged from the pin. The removal lever is rotated to remove the taper pin from the terminal block socket.

In order to maintain the reliability of the system, it is imperative that the taper pin insertion tool be used for inserting the taper pins in the terminal block sockets. Inserting the pins into the sockets with fingers or pliers will not make them stay. They must be driven in with the insertion tool. The tool must be calibrated

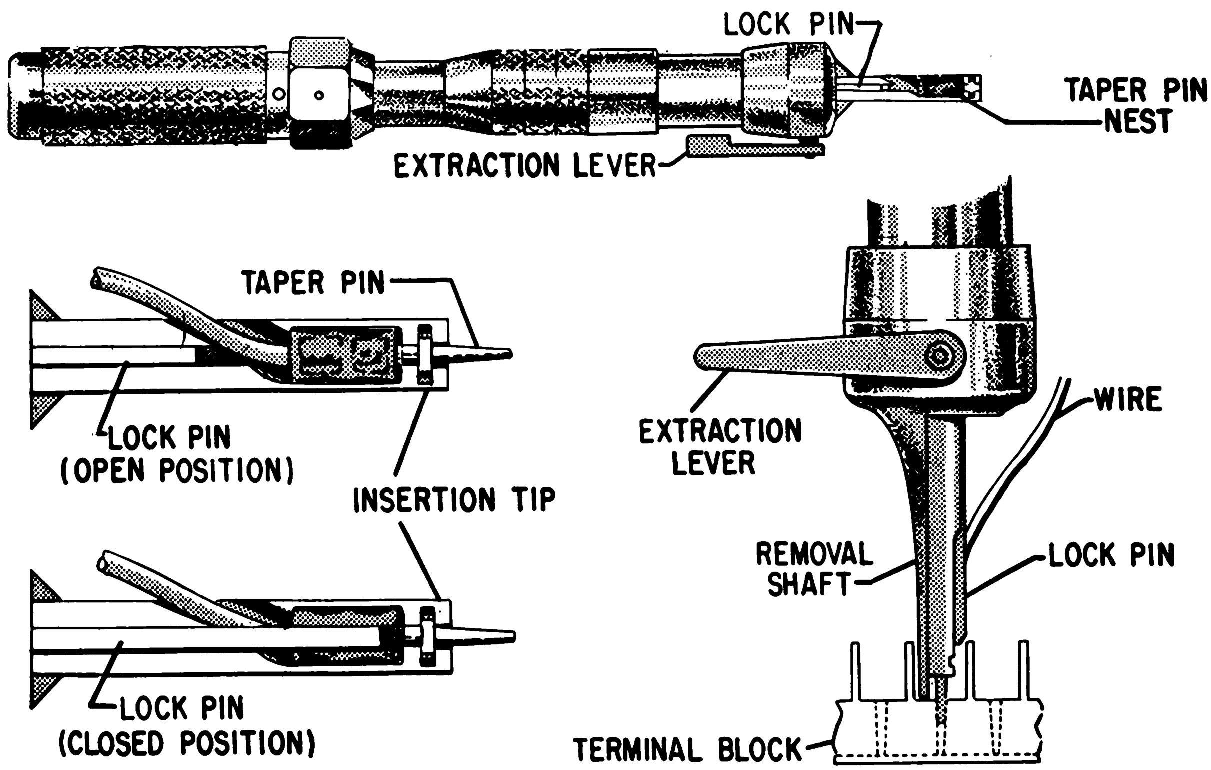


Figure 22-5.—Taper pin insertion and removal tool.

to insure that the proper pressures are used. When inserting the taper pins, the insertion tool must be held at right angles to the terminal block, and pushed straight toward the terminal block without twisting the tool. The pins are very sensitive to twists, which could cause a faulty connection or a broken pin. Bent or broken pins should always be replaced. However, if correct installation procedures are followed, a taper pin may be installed and removed 25 times before replacement is necessary. A properly installed taper pin will pass the pull test of the insertion tool.

Three different sizes of taper pins are used to terminate wires from size 16 through size 22. The sizes are identified by color coding of the insulating sleeves.

Taper Pin Crimping Tool

A crimping tool (fig. 22-6) is used to attach the taper pin to the wire. This taper pin crimping tool is similar to other types of wire terminal crimping tools.

Soldering

The AE must exercise considerable care when soldering leads in components that contain miniature tubes and parts. Small resistors, capacitors, connecting wires, and other similar parts are placed in close proximity in many subassemblies; while soldering one part, it is very easy to damage those parts nearby. In the preparation of the work for soldering, it is necessary to use tools of correct size. Small jeweler's pliers and side cutters are available through supply channels and should be used when working on miniature subassemblies. Large handtools present a hazard in this type of work and their use should be avoided.

Soldering irons should have wattage ratings high enough to provide sufficient heat for making good connections but not so large as to cause overheating and damage to adjacent parts. A pencil type iron with a tip small enough for work in confined spaces is generally preferable for

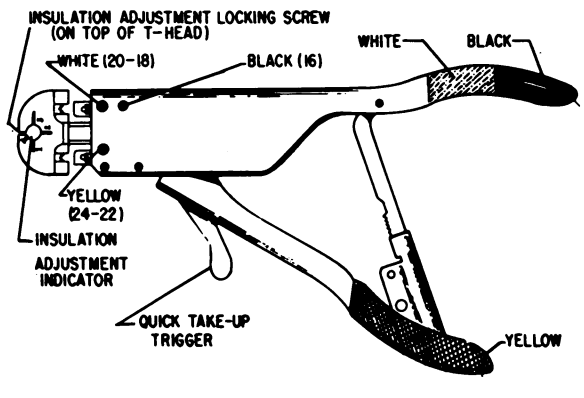


Figure 22-6.—Taper pin crimping tool.

work with small components, though many connections such as those made to ground terminals must be made with an iron of larger capacity.

The use of soldering irons and the proper procedures for soldering are discussed in chapter 14 of this course. The AE should also review the applicable chapter in Basic Electricity, NavPers 10086-A, for correct soldering techniques.

Thermal Shunt

Overheating and damage of miniature resistors and capacitors can be avoided only by restricting the conduction of heat to the metal leads and preventing it from flowing into the body of the part. This can be accomplished by using a thermal shunt. The term "shunt," as used here, is not intended to imply that the heat returns to the lead at some other point in the same way that current does when using an electrical shunt. The heat is dissipated into the surrounding air when using a thermal shunt. The point is, much of the heat is turned aside (shunted) and is not allowed to enter the part.

A simple and frequently used method of providing a thermal shunt is to grip the lead between the body of the miniature part and the terminal with a pair of long-nosed pliers. The metal jaws form a low-resistance heat path which funnels the flow of heat away from the part. This method has certain disadvantages; it is awkward to solder with one hand and, even more important, the technician may have a tendency to release the pliers upon removing the soldering iron and permit an unrestricted flow of heat into the part from the still molten solder. Also, steel pliers do not possess the degree of heat conductivity required for effective shunting or full protection against damage.

A more effective heat shunt is provided by a clamp, made of copper, which can be left attached to the lead until the joint cools. A good clamp shunt can be made easily by sweating small copper bars into the jaws of an ordinary alligator clip. A shunt of this type is shown in figure 22-7.

A clamp type heat shunt should be used when soldering the leads of small capacitors, resistors, and choke coils. The clamp should be placed near the body of the part and as far as possible from the joint being soldered. Care should be taken to avoid the formation of a low-resistance heat path between the hot soldered connection and the part. Do not allow the clamp to contact both.

The effectiveness of the heat shunt can be maintained by keeping the jaws flat and free from dirt, grease, or soldering flux so that a good contact between the clamp and the metal lead is insured. The face of the clamp turned toward the iron should be kept bright to minimize heat transfer by radiation, while the rest of the clamp body should be dull black in color.

Brush Contouring Device

The discussion that follows describes a brush contouring device that can be easily constructed in most electric shops. If properly used, it will insure proper brush seating and also save much time. Should the AE decide to construct one of these devices, he may not want to follow the exact procedure outlined here. However, the information that is given should prove helpful as a guide.

Figure 22-8 shows the disassembled parts that are needed for constructing the device, and figure 22-9 shows an assembled view.

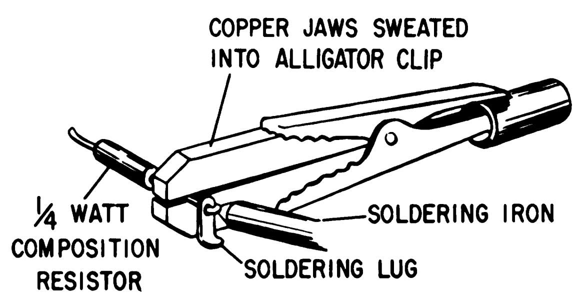


Figure 22-7.—Details of a clamp type heat shunt.

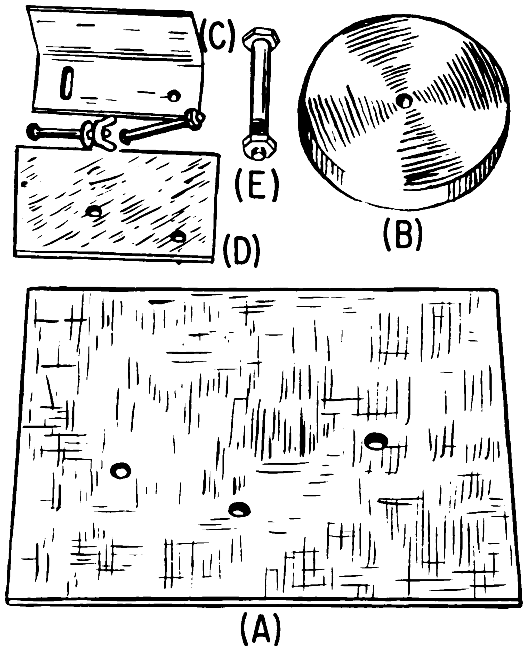


Figure 22-8.—Parts required for contouring device.

The following materials are needed (refer to fig. 22-8):

1. One piece of laminated plastic (A), 4 x 6 x 1/2 inches.
2. One brass disk (B), 1 inch thick, drilled in the center to receive a bolt for mounting.
3. One piece of angle aluminum (C), 1 x 1 x 2 1/2 inches.
4. One piece of 1/8-inch plastic (D), 2 1/2 x 3 inches.
5. One bolt (E), for mounting the disk, and two instrument mounting screws. One of these screws is to be fitted with a wingnut.

Part (B) must be turned on a lathe since its diameter is critical. This part must have the same diameter as the commutator or slipring for which the brush is being fitted.

The following steps should be used when contouring brushes:

1. Loosen the adjusting bolt in the elongated slot in part (C).
2. Using an old brush removed from the generator, motor, or electrical starter, place the brush against the angle aluminum, part (C), adjusting the angle until the brush contacts the brass disk throughout its contoured surface. Lock part (C) with the wingnut. CAUTION: Use only properly seated brushes (that is, brushes that have been in use for many hours of operation) for step 2.
3. One person then holds a strip of very fine sandpaper, 1 inch wide, on the outer diameter of the brass disk, and pulls the ends alternately back and forth, keeping the sandpaper taut. The other person holds a new brush against part (C) and pushes lightly against the sandpaper until the proper contour is formed on the brush end. NOTE: Be careful to keep the brush tight against part (C) during contouring.

By contouring brushes with this device instead of letting them "break in" on the generator, all carbon, dust, grit, etc., (normally produced as the new brush becomes seated) are kept out of the generator. Moreover, the brush surface is contoured at the correct angle with respect to the longitudinal axis of the brush. With the device, less run-in time is required, there is less chance of generator failure due to brushes heating, and excessive commutator and slipring wear is eliminated.

USE AND CARE OF SHOP TOOLS

Good working habits dictate proper use of shop tools. In general, the same care and good use of the tools in the individual's toolbox also apply to shop tools.

Tools should be cleaned and inspected after the job has been completed. Return all the shop tools to their proper storage bins. If a tool becomes worn, damaged, or broken, report it to the senior member of the shop so that proper steps may be taken for replacements or repairs.

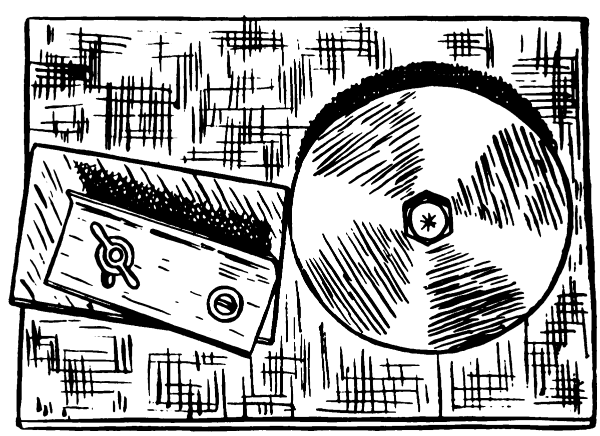


Figure 22-9.—Assembly of contouring device.

INVENTORY REQUIREMENTS

The basic objective of an inventory is to insure a proper balance between the supply of, and the demand for, those tools required for the efficient operation and maintenance of a squadron or maintenance activity. To accomplish this objective it is necessary that tools be identified and cataloged to provide accurate knowledge of the tools being used. Each item should be accounted for every 30 to 90 days in accordance with squadron instructions. The number of handtools on hand in relation to the number required by the activity should be indicated by the inventory.

REORDERING TOOLS

Shop tools are reordered as the inventory requirements dictate. Usually the senior petty officer or his delegate reorders all tools, both shop tools and those for individual toolboxes, as they are needed. However, squadron or maintenance activity policy is followed in all cases.

SQUADRON TOOL CRIB

A squadron tool crib is often established under the responsibility of the maintenance department. The purpose of a tool crib is for the stowage and issuance of handtools that are of low usage and are common to more than one shop. Many special tools which are provided by the aircraft manufacturer are also stowed in the tool crib. A complete list of these special tools can be found in the Maintenance Instructions Manual, section one, for each type of aircraft.

Typical of the special tools found in the tool crib is the screwdriver shown in figure 22-10. It is used to regulate the transmitter adjusting screw in the elevator trim tab actuator of an S-2D aircraft.

Frequently a squadron tool crib has the responsibility for all tools in the squadron. This includes issuance, inventory of toolboxes, and ordering new tools for replacement of broken or lost tools.

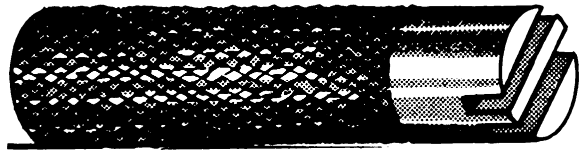


Figure 22-10.—Special screwdriver.

HANDTOOL SAFETY

Carelessness is the greatest menace in any shop. It must come from the man himself; the machine alone cannot inflict injury. Lack of care is the cause of most accidents in electrical and electronics shops today.

It should be remembered that all moving machinery is potentially dangerous. It is dangerous to lean against any machine that is in motion, or that may be started in motion by anyone else. Treat a machine with businesslike respect and there is not need to fear it. Do not start a machine until its operation has been fully explained by a competent instructor.

Listed below are a number of precautions to be observed when using various tools:

1. Never use the hand to hold a piece of work on a drilling machine; use a vise or a clamp.
2. Be sure to use the guard over a grinding wheel. If it is necessary to work with the guard off the wheel, stand to one side in order to avoid flying particles of emery. When grinding screwdriver blades or other metals on a grinding wheel, always use safety goggles. While using a rest to grind parts or tools, be sure that the rest is close to the grinding wheel.
3. Never use a file without a handle.
4. Report promptly to the shop first aid supervisor any cut or bruise.
5. While in use, tools should be arranged so that they can easily be reached.
6. Tools will break if allowed to fall from a height, and the possibility of bodily injury to someone is always present. A tool belt should be used when working where tools can fall overboard or fall from a height.
7. Do not leave tools where they can be stepped on, or let them protrude from workbenches, because of the possibility of injury to other personnel. For the same reason, use commonsense about carrying tools in pockets.
8. Never work with a hammer that has a loose head. This is dangerous because the hammer head may fly off and cause an injury. If the wedge comes out, replace it before continuing to use the hammer.

CHAPTER 23

LINE AND SHOP MAINTENANCE AND TESTING

The quality of materials used on naval airborne electrical and ground test equipment is the best available for its purpose. Sound design is also insured by building this equipment to rigid specifications, by testing it thoroughly before it is purchased by the Navy, and by observing field performance closely.

Even with such rigid specifications, testing, and evaluating, machinery will not function without some degree of maintenance and adjustment by the people who use it. This is especially true with aircraft where there is little tolerance in the performance of the equipment. All the equipment on an aircraft is carefully checked and adjusted before it leaves an overhaul activity or the factory, so that it arrives in the squadron ready for use. To maintain the aircraft in this condition is the job of squadron personnel.

AIRCRAFT PLUMBING

Rigid and flexible tubing are the two most common types used in aircraft. These tubes are manufactured in many different sizes; sizing is usually determined by outside diameter and ranges from 1/8 inch to 2 inches. The amount of pressure that a tube can safely withstand is determined by the type of material and the wall thickness. Use caution when replacing or repairing tubing to insure that the proper type is used. Detailed information on tubing and tubing repairs may be found in Aircraft Structural Hardware, NW 01-1A-8.

RIGID TUBING

Rigid metal tubes are widely used in aircraft for fuel, oil, coolant, oxygen, instrument, hydraulic, and vent lines. Tubing of copper, corrosion-resistant steel (stainless steel), and aluminum alloy is used. The basic tube material may be identified by either visual inspection or, as in the case of aluminum alloys, the actual alloy designation may be stamped on the surface of the tubing.

While it is difficult to generalize as to the specific material application, copper has been replaced as a general-purpose material by aluminum alloys, because of its lighter weight, workability, and resistance to corrosion and fatigue.

Tube fittings are required when connecting tubes together or when connecting a tube to an instrument. These are made from aluminum alloy, steel, copper base alloys, or rubber. The shape of the fitting is determined by the particular installation—some are straight, while others are made at various angles. Fittings are secured to the tubes by using a beaded or flared joint. The beaded or upset joint is used in low-pressure lines, such as those found in vacuum, deicer, and oil systems where rubber hose fittings are utilized. Flared joints are used on all high-pressure and some low-pressure lines. Metal fittings are always used. Grip dies and flaring or beading tools are required to form flared and beaded joints. When working with rigid tubing, consult the manuals on the beading and flaring tools for instructions on the proper use of the tools.

Damaged piping and lines should be replaced with new parts. When repairing tubing, the length removed will be determined by the location and extent of the damage and the most convenient location for tool manipulation. To prevent damage by a misfit and to insure a leakproof system, be sure to use the correct size and proper type of coupling and fitting.

There is a tendency to overtighten tubing nuts to insure that high-pressure fluid will not escape. Such overtightening may severely damage or completely cut off the tube flare. If, upon the removal of a tube, a flare is found

to retain less than 50 percent of its original wall thickness, it should be rejected.

In bending tubing, care must be exercised to prevent the collapsing of the tube at the bend. Bending may best be accomplished by using the bending tool. All aluminum and aluminum-alloy tubing requiring bending should be bent by a bending machine. Most aluminum-alloy tubing must be annealed before bending. Do not use torch, or flame on tubing because excess heat will destroy the strength of heat-treated tubing.

When making bends for fluid tubing, be certain that you use the proper bending radius. These specifications are given in NW 01-1A-8.

Rigid Line Identification

Each rigid line in the aircraft is identified by bands of paint or strips of tape around the line near each fitting. These identifying media are applied at least once in each compartment. Various other information is also applied to the lines.

Identification tapes are applied to all lines less than 4 inches in diameter except cold lines, hot lines, lines in oily environment, and lines in engine compartments where there is a possibility of the tape being drawn into the engine intake. In these cases, and all others where tapes should not be used, painted identification is applied to the lines.

Identification tape codes indicate the function, contents, hazards, direction of flow, and pressure in the fluid line. These tapes are applied in accordance with MIL-STD-1247. This standard was issued in order to standardize rigid line identification throughout the Department of Defense. Figure 23-1 illustrates the method of applying these tapes as specified by this standard.

The function of a line is identified by use of a tape, approximately 1 inch wide, upon which word(s), color(s), and geometric symbols are printed. Functional identification markings, as provided in MIL-STD-1247, are the subject of international standardization agreement. Three-fourths of the total width on the left side of the tape has a code color or colors which indicate one function only per color or colors. The function of the line is printed in English across the colored portion of the tape; therefore, even a non-English-speaking person can troubleshoot or maintain the aircraft if he knows the code but cannot read English. The right-hand one-fourth of the functional identification tape contains a geometric symbol which is different for every function. This is to insure that all technicians, whether English speaking or not, who may be colorblind may still be able to positively identify the line function by means of the geometric design rather than by the color(s) or word(s). Figure 23-2 is a listing, in tabular form, of functions and their associated identification media as used on the tapes.

The identification-of-hazards tape shows the hazard associated with the contents of the line. Tapes used to show hazards are approximately 1/2 inch wide, with the abbreviation of the hazard contained in the line printed across the tape. There are four general classes of hazards found in connection with fluid lines. These hazards are outlined in the following paragraphs.

Flammable Material (FLAM). The hazard marking "FLAM" is used to identify all

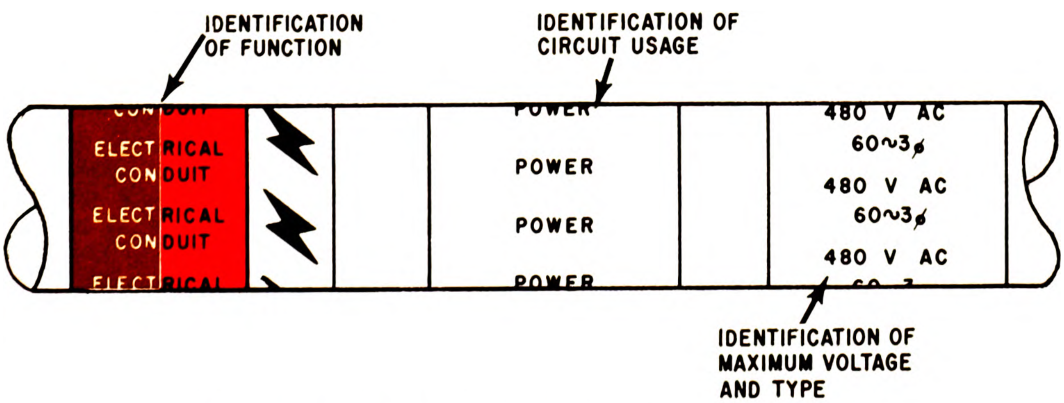


Figure 23-1.—Electrical line identification application.

materials known ordinarily as flammables or combustibles.

Toxic and Poisonous Materials (TOXIC). A line identified by the word "TOXIC" contains materials which are extremely hazardous to life or health.

Anesthetics and Harmful Materials (AAHM). All materials productive of anesthetic vapors and all liquid chemicals and compounds hazardous to life and property, but not normally productive of dangerous quantities of fumes or vapors, are in this category.

Physically Dangerous Materials (PHDAN). A line which carries material which is not dangerous within itself, but which is asphyxiating in confined areas or which is generally handled in a dangerous physical state of pressure or temperature, is identified by the marking " PHDAN."

Table 23-1 lists some of the fluids with which the AE may be required to work and the hazards associated with each.

Table 23-1.—Hazards associated with various fluids.

Contents	Hazard
Air (under pressure)	PHDAN
Alcohol	FLAM
Carbon dioxide	PHDAN
Freon	PHDAN
Gaseous oxygen	PHDAN
Liquid nitrogen	PHDAN
Liquid oxygen	PHDAN
LPG (liquid petroleum gas)	FLAM
Nitrogen gas	PHDAN
Oils and greases	FLAM
JP-4	FLAM
Trichlorethylene	AAHM

FLEXIBLE TUBING (HOSE)

Flexible hose assemblies, which consist of lengths of hose that are coupled with threaded end fittings, may be divided into two major groups—high pressure and low pressure, according to their application.

The specifications of a flexible hose may be obtained by interpreting the identification code that is printed on the hose. This identification, which is a series of dots and dashes, gives the hose size, temperature range, and date of manufacture in quarter of year and year. Refer to NW 01-1A-8 for a detailed discussion of flexible hose identification.

High-pressure flexible hose cannot be made up locally; it must be ordered through regular supply channels. The reason for this is that this hose must be subjected to high-pressure tests. Squadrons are not allowed to make such tests.

The parts that make up a low-pressure flexible hose may be ordered through supply and made up locally. Fittings from damaged hose may be reused provided they meet the required specifications; however, at no time other than for an emergency repair should hose that has already been used be reinstalled.

Never, under any conditions, use oil on self-sealing hose as an aid to installation. Oil or water may be used on most other types of fuel, oil, and coolant hose when installation is made; however, oil ONLY is used on hydraulic and pneumatic hose.

Hose should be installed so that it will not be subjected to twisting under any condition of operation. This type installation lessens the tendency for connecting fittings to loosen. When replacing hose in hydraulic, fuel, oil, alcohol, and pneumatic systems, the hose installed must be a duplicate of the hose removed as to length, outside diameter, inside diameter, material, type, and shape (except on directed modifications).

If a bend is required when installing hose in fluid systems, the radius must not be smaller than the minimum specified in NW 01-1A-8. This publication shows the minimum bend radii for flexible hose. When practical, it is desirable to use a radius that is larger than the specified minimum.

When hose is installed through holes in brackets, and when supporting clips are used, there must be no reduction in the diameter of the hose. If these conditions are present, the flow will be reduced and damaged to the hose may occur.

Hose must be supported at least every 24 inches. Closer supports are desired when practical. The support of a flexible line should be such that it will never tend to cause deflection of the rigid connecting lines under any possible relative motion that may occur. Flexible hose between two rigid connections may have excessive motion restrained where necessary but should never be rigidly supported.

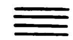
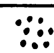
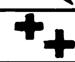
FUNCTION	COLOR	SYMBOL
Fuel	Red	
Rocket Oxidizer	Green, Gray	
Rocket Fuel	Red, Gray	
Water Injection	Red, Gray, Red	
Lubrication	Yellow	
Hydraulic	Blue, Yellow	
Solvent	Blue, Brown	
Pneumatic	Orange, Blue	
Instrument air	Orange, Gray	
Coolant	Blue	
Breathing Oxygen	Green	
Air Conditioning	Brown, Gray	
Monopropellant	Yellow, Orange	
Fire Protection	Brown	
De-Icing	Gray	
Rocket Catalyst	Yellow, Green	
Compressed gas	Orange	
Electrical Conduit	Brown, Orange	
Inerting	Orange, Green	

Figure 23-2.—Functional identification tape data.

Chafing may be avoided by using suitable bulkhead type grommets or cushioned clips.

Protect hose installations from excessive temperature, such as exhaust blasts, supercharger ducts, and the like, either by shrouding or relocation. Use of flame-resistant hose is preferred forward of the firewall and is directed by BuWeps instructions on certain aircraft.

Where hose connections using hose and hose clamps are made to an engine or to engine-mounted accessories, the hose must be installed so that 1 1/2 inches of slack or an adequate bend is provided between the last point of support and the attachment to the engine or accessory. This prevents the possibility of the hose being pulled off the nipple due to engine movement.

Whenever possible, hose should be installed so that all markings on the hose are visible. All hose are manufactured from materials subject to deterioration by exposure to heat, sunlight, excessive moisture, and ozone. Accordingly, hose should be stored in a cool dry place and away from electrical equipment. Age limits of shelf items based on the manufacturer's code can be obtained from the current accessory bulletins. Hose must be stored in straight lengths to prevent it becoming set in a curved position. Peeling, flaking of the hose

cover, or exposure of the braid reinforcement to the elements is cause for replacement of the hose.

COAXIAL CABLE AND CONNECTORS

Some instrument circuits employ a-c signal voltages which are extremely sensitive to external electrical influences. One such system is the fuel quantity indicating circuit. This circuit senses, amplifies, and indicates changes in the capacitance of capacitor units that are immersed in the fuel in the aircraft's fuel cells. A small change in the capacitance of these units produces a relatively large change on the dial of the fuel indicator. For this reason, the conductors which carry a-c signal voltages from the tank capacitor units to the fuel quantity amplifier must be coaxial cable. This cable, because of the way it is constructed, prevents the induction of error voltages into the signal-carrying wire. These errors, in noncoaxial conductors, would be caused by such effects as stray capacitance between the signal-carrying wire and ground or voltages induced from nearby magnetic fields. These errors would probably be very small in themselves, but would be amplified along with the normal signals and thus cause incorrect indications on the fuel quantity indicator.

Figure 23-3 (A) shows the construction of a coaxial cable. The outer jacket provides protection against moisture and abrasion. Note that the center conductor, which carries signal voltages, is surrounded by a braided metallic shield. This shield protects the center conductor from stray magnetic induction by passing these voltages to ground. The center conductor and shield are insulated from each other by the dielectric material. The braided shield is conductive, and is connected to ground at both ends of the coaxial cable. There is a certain amount of capacitance between the shield and center conductor. Corrections for this capacitance can be easily made since the amount of capacitance can be easily determined. The amount of capacitance can be determined because the distance between the shield and center conductor is uniform all along the cable. The amount of capacitance is determined by the thickness of the dielectric. Each linear foot of cable has a fixed amount of capacitance. The total capacitance of a length of coaxial cable equals the capacitance per linear foot times the total number of feet.

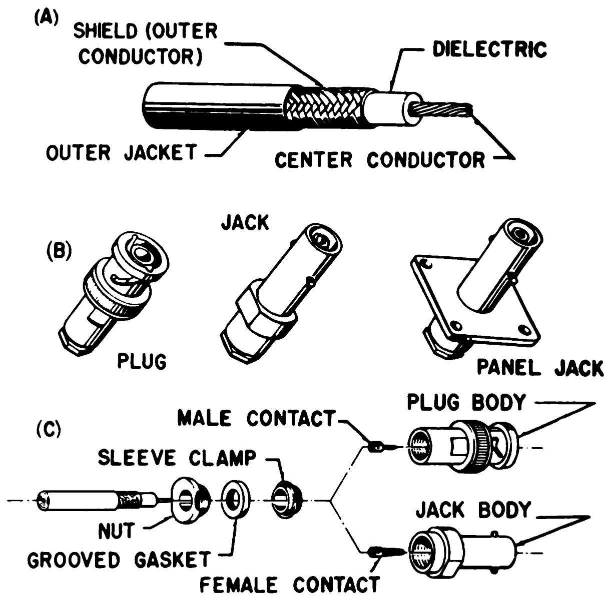


Figure 23-3.—(A) Coaxial cable: (B) coaxial connectors; (C) coaxial connector hookup.

Because of the construction and performance requirements of coaxial cable, a special type of coaxial connector is used. The type of connector with which the AE usually works is shown in figure 23-3 (B). A coaxial connector provides a dependable means of grounding the cable's metallic shield. This ground is made through the connector's shell (body). The connector's center contact is insulated from the surrounding shell, and provides contact for the cable's center conductor. It is important that the cable's center conductor never becomes grounded. Figure 23-3 (C) shows how a coaxial cable and connector are assembled. Note that the plug connector uses a male contact and the jack connector uses a female contact.

INSTRUMENT FIELD TESTING

Testing equipment is a valuable asset to the AE as an aid in performing necessary operational checks on instruments and instrument systems. The ability to properly use instrument test equipment is very important to the AE. When using field testing equipment, certain procedures must be followed to prevent damage to both the test equipment and the instrument system being checked.

The most widely used test equipment is discussed in this chapter. Detailed information and operating instructions, for each type of equipment may be found in the Operation Instruction Manual for the particular equipment.

Aircraft instrument systems are divided into two main groups—electrical and mechanical. Some of the electrical instrument systems that require test equipment are the fuel quantity system, the thermocouple thermometer system, the resistance bulb thermometer system, the tachometer system, and synchro systems. One of the mechanical instrument systems that requires test equipment is the pitot static system. This includes the airspeed indicator, rate-of-climb indicator, and the altimeter.

VP-2 VACUUM PRESSURE TESTER

The VP-2 Vacuum Pressure Tester (fig. 23-4) is designed to provide a fast, reliable,

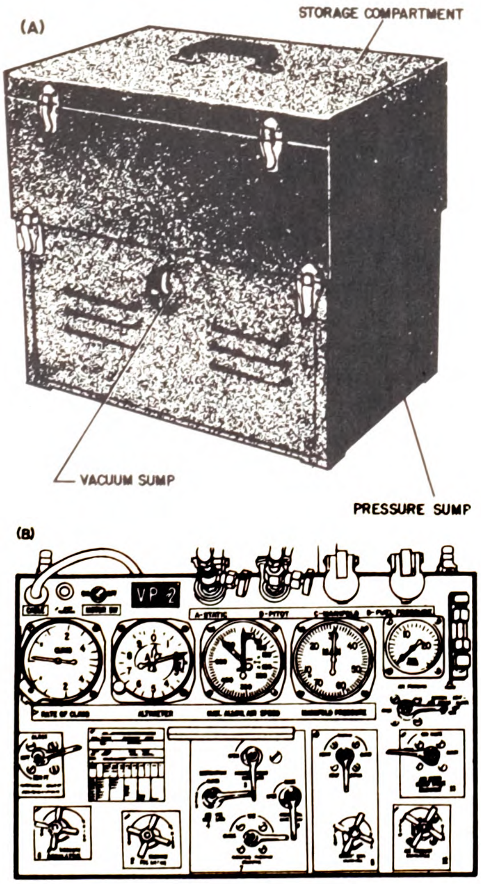


Figure 23-4.—VP-2 tester. (A) Complete unit; (B) instrument panel.

and convenient means of testing at the aircraft the following instruments:

1. Rate-of-climb indicators.
2. Airspeed indicators.
3. Altimeters.
4. Manifold pressure gages.
5. Fuel pressure gages.

The tester supplies air pressure and suction, both of which are controlled by means of valves. The suction or pressure is applied simultaneously to the aircraft's instrument and to a similar master instrument on the panel of the tester. Any fault is indicated by a difference in reading between the master instrument and aircraft instrument.

The test unit is powered by a continuous service 1/20-hp, 115- volt, 60- cycle a-c or d-c universal motor, which is controlled by a toggle switch. A 5-ampere cartridge fuse protects the motor against electrical damage.

A booklet containing detailed operating instructions is attached to the instrument panel. This booklet sets forth the exact procedure for testing each instrument or system. Calibration cards are also furnished for each master instrument.

Some of the important details to consider when operating the VP-2 tester are as follows:

1. Follow operating instructions exactly.
2. Prepare the set for test with the motor switch OFF.
3. Before starting the motor, check the zero reading of all instruments.
4. Never attempt to change the settings of valves with the motor ON.
5. Stop the motor after each test.
6. All the instrument hands to return to zero before disconnecting test hoses or before starting another test.

If possible, practice using the VP-2 tester with a spare instrument. This allows the individual a chance to feel the operation of the needle valves which control the pressure and suction to the instrument being tested. For additional information on the operation and service of the VP-2 vacuum pressure tester, refer to NA 17-15C-504.

TRJ-2 TACHOMETER TESTER

The TRJ-2 Tachometer Tester is designed to provide a fast, reliable, and convenient means of testing aircraft tachometer indicators and generators at the aircraft. The test equipment is used to produce simultaneous readings

on the master tachometer indicator and on the aircraft's indicator.

The tachometer generator is removed from the aircraft engine and mounted on the tester. During the test, the generator is driven at various speeds by the tester. The electrical output of the generator is connected to the aircraft's tachometer indicator and to a master tachometer indicator on the tester. By comparing the readings of the master indicator to the readings of the aircraft's indicator, any error may be detected. An obvious advantage in this method of testing is that the aircraft engine does not have to be operated.

Figure 23-5 shows a TRJ-2 tester with a tachometer generator attached ready for testing.

The tester is powered by a 3/16-hp universal gear-head motor and may be operated from either 115-volt d.c. or 115-volt, 60-cycle, single-phase a.c. The motor is connected by an adapter to a train of gears called the transmission. There are two power takeoffs on the transmission which drive the tachometer generators that are under test. Either screw or pad type mounted generators may be tested by using adapters furnished with the tester. One of the takeoffs is used for 4-pole generators and is geared to run at shaft speeds up to 2,310 rpm. The other is used for 2-pole generators and is geared to run at shaft speeds up to 4,620 rpm. On the inner side of the transmission, opposite the power takeoffs, are mounted a 2-pole and a 4-pole tachometer generator. The 2-pole generator is connected to an indicator calibrated in "percent rpm." The 4-pole generator is connected to an indicator calibrated in rpm only. These connections are made through receptacles on the face panel of the tester.

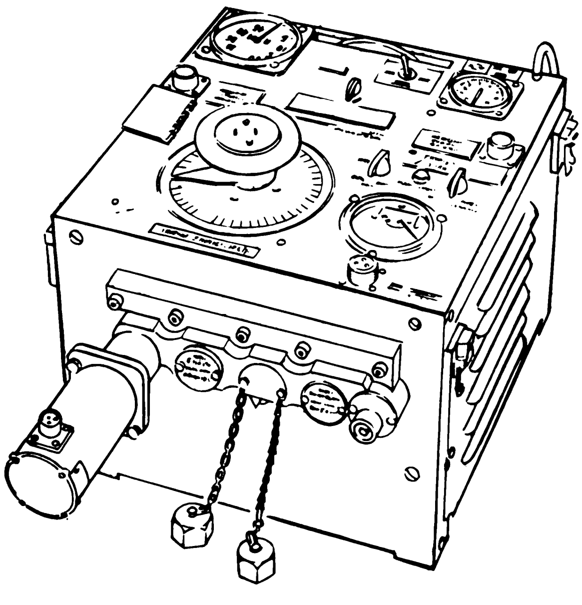


Figure 23-5.—TRJ-2 tester with tachometer generator attached.

The tester drive motor is controlled by a toggle switch, and powered through a 5-ampere fuse. Two wiring harnesses are included with the tester. One harness is 30 inches long, and the other is 25 feet long. Any combination of test hookups can be made with these harnesses. These harnesses are designed so that they can be connected to any combination of pin receptacles of two or three generators or indicators.

The electrical speed control is accomplished by means of a rangefinder, consisting of a 60-ohm rheostat adjusted by a control knob on the panel.

For additional information on the operation and service of the TRJ-2 tester, refer to NA 17-15C-505.

MAGNESYN TEST TRANSMITTER

The Magnesyn test transmitter unit provides a standard against which single Magnesyn indicator may be calibrated. The calibrated dial of the test transmitter provides a reference for checking the readings of the indicators. The Magnesyn tester is connected electrically to the aircraft's Magnesyn system. This is done by removing the electrical connector from the aircraft Magnesyn transmitter and connecting it to the test unit. The degree indicator on the test transmitter is set to a position that is within the range of the Magnesyn system being tested. The aircraft Magnesyn indicator should aline itself with the setting on the test unit; if it does not, the system is defective.

The Magnesyn transmitter may be rotated through 360°, by means of the cam and gear drive, to transmit to the instrument under test the desired degree of rotation. A self-contained d-c source is enclosed in the transmitter case to provide a voltage of correct polarity to check electrical zero of the instrument under test. Figure 23-6 (A) shows the Magnesyn test transmitter; figure 23-6 (B) shows the accessory cables.

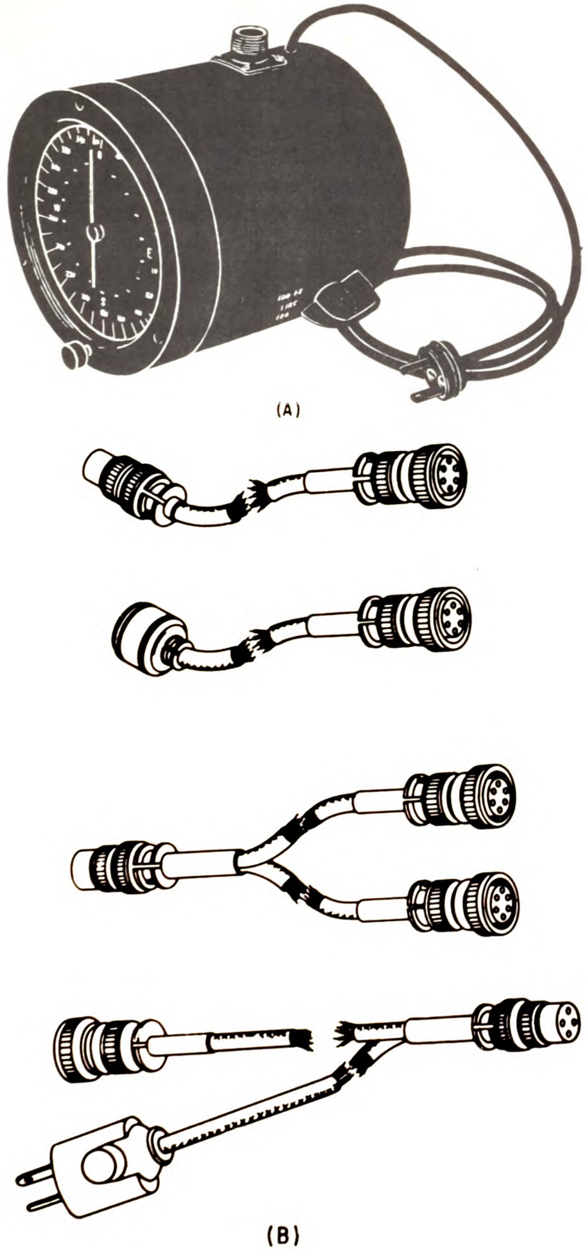


Figure 23-6.—(A) Magnesyn test transmitter; (B) accessory cables.

The Magnesyn test transmitter is completely self-contained except for external excitation voltage. To set up the transmitter for operation, move the test selector switch knob to OFF. Connect the power cord to a suitable source of 26-volt, 400-cycle, single-phase power.

Single Magnesyn indicators are connected to the test transmitter by means of a cable. The 6-pin connector goes to the transmitter, and the 4-pin connector to the indicator. Dual indicators are connected to the test transmitter by means of a different type of cable. The 7-pin connector goes to the indicator. To test the right-hand Magnesyn of dual side-by-side indicators, plug the 6-pin connector marked right or front into the test transmitter. To test the left-hand Magnesyn of dual side-by-side indicators, plug the 6-pin connector marked left or rear into the test transmitter.

For scale error and friction tests, turn the test selector switch knob to TEST. Move the transmitter pointer as required by means of the pointer setting knob on the bezel.

To establish the electrical zero position of the indicator under test, move the test selector switch to IND. E.Z. This disconnects the test transmitter from the indicator and applies correctly polarized d-c voltage from the two dry cells located in the transmitter housing.

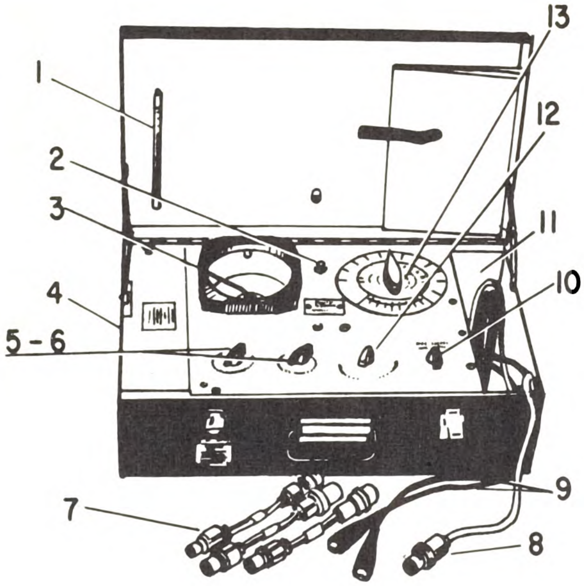
Upon completion of the tests, disconnect the cables from the test transmitter and indicator. Shut off the test transmitter when not in use by turning the test selector switch to OFF. The unit may be left in this condition whenever it is not in use since all excitation circuits are disconnected.

ELECTRICAL THERMOMETER TESTER TYPE N-3

The N-3 tester (fig. 23-7) is a portable precision instrument for checking scale errors and calibrating aircraft thermocouple thermometers and electrical-resistance thermometers.

The tester contains a dual-purpose precision standardizing voltmeter (3). This meter is used to determine the voltage applied when testing electrical-resistance type thermometers, and for determining the correct current setting when testing thermocouple thermometers. Adjusting rheostat (5) is used to adjust the tester voltage when testing resistance thermometers. Adjusting rheostat (6) is used to make current adjustments when testing thermocouple thermometers. Adjust these rheostats until the voltmeter pointer is on the red line at the right end of the scale arc.

The conventional thermocouple thermometers used in naval aircraft have an external resistance of either 8 or 22 ohms. The resistance and voltage selector switch (12) is used to connect either resistance value, as



1. Liquid-in-glass thermometer.
2. Battery cutoff switch.
3. Standardizing voltmeter.
4. Battery compartment.
5 & 6 Adjusting rheostats.
7. Adapters for connecting ratiometers.
8. Ratiometer test lead.
9. Thermocouple thermometer test leads.
10. Left and right switch.
11. Accessory and lead compartment.
12. Resistance and voltage selector switch.
13. Temperature selector switch.

Figure 23-7.—Electrical Thermometer Tester Type N-3.

required, for the thermocouple thermometers under test. This switch has, in addition, a zero-ohms aircraft-test position. When placed in this position, it cuts out both the 8 and 22 ohms resistance. At the same time it cuts in the external resistance (leads and thermocouple) of the aircraft system.

The left and right switch (10) is used for element selection according to the indicator under test. The first position is used when checking single indicators, or the left side of dual indicators. The second position is used when checking the right side of dual indicators. A safety cutoff switch opens the battery circuits when the lid is closed.

A liquid-in-glass thermometer is clipped to the lid and is used to determine ambient temperature when testing thermocouple thermometers.

The temperature selector switch (13) is used to select the appropriate millivoltage to be applied to the thermocouple thermometers under test. These are selected in accordance with the temperature calibration point selected from the outer ring of figures on the dial. At the same time, the proper type system is selected. The system is either the iron-constantan (yellow sector), copper-constantan (red sector), or chromel-alumel (green sector). A different range is provided for each system.

The flexible, rubber-covered clip leads used to connect the thermocouple thermometers to the tester are in series with the tapped shunt, the selected series resistance, and the indicator. The flexible leads must not be lengthened or shortened since their resistance is critical.

MEASURING EXHAUST GAS TEMPERATURE

Exhaust gas temperature and engine speed are two of the most important factors affecting jet engine life and safe operation. A few degrees of excess exhaust gas temperature will reduce engine life as much as 50 percent, and low exhaust gas temperature materially reduces jet engine efficiency. Excessive engine temperature usually is an indication of some system malfunction. The most common cause of excessive temperature is a malfunction of the fuel control system. The most common result of this malfunction is engine overspeeding.

A jetcal analyzer is used to determine the accuracy of the aircraft exhaust gas temperature (tailpipe temperature) system without running the engine. It is also used to read engine speed accurately during engine runup. The jetcal analyzer will functionally check the aircraft's exhaust gas temperature (EGT) system, without operating the engine, to determine if the system is within prescribed tolerance. If the EGT system is not within tolerance, the jetcal analyzer will aid in troubleshooting and also help to isolate system errors.

Incorporated in the analyzer is the TAKCAL unit (rpm indicator) check circuit, the purpose of which is to read engine speed with an accuracy of ±0.1 percent during engine operation. An additional use of the TAKCAL unit check

circuit is to troubleshoot the aircraft's tachometer system. After the exhaust gas temperature and engine speed systems have been tested for accuracy and any malfunctions corrected, the operator may use selected portions of the jetcal analyzer circuits to establish the proper relationship between exhaust gas temperature and engine speed. Figure 23-8 shows a typical jetcal analyzer.

The jetcal analyzer requires a power supply of 95 to 135 volts, 50 to 400 cycles a.c., and will operate in temperatures from minus 55° C to plus 70° C. A 95- to 135-volt a-c power supply must be used for the TAKCAL unit check and the thermocouple check. All other operations can be performed by using emergency batteries when an external power supply is not available. The batteries are actuated by a pushbutton switch. When the switch is released, the batteries are out of the circuit. However, the switch can be depressed when using 95- to 135-volt a.c without damage to the batteries. To preserve the life of the emergency batteries, use an external a-c power supply whenever possible.

The jetcal analyzer has eleven primary and separate functions. They are as follows:

1. To functionally check the entire jet aircraft exhaust gas temperature system for error without running the engine or disconnecting the wiring.
2. To check individual thermocouples before placing them in the aircraft.

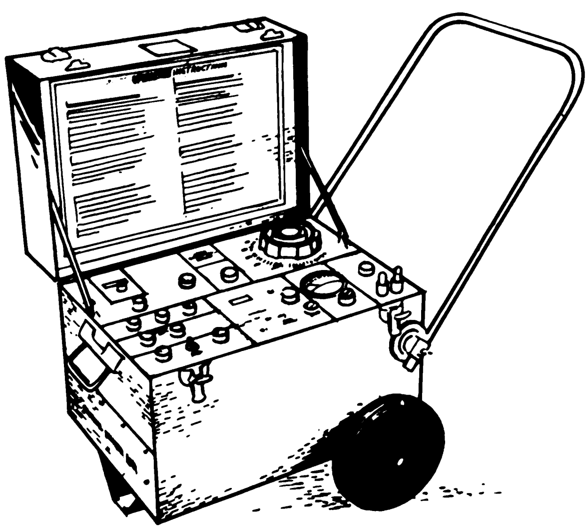


Figure 23-8.—Jetcal analyzer.

3. To check each engine thermocouple for continuity.
4. To check the thermocouples and harness for accuracy of output.
5. To check the resistance of the EGT circuit, without the EGT indicator, to within allowable limits.
6. To check the insulation of the EGT circuit for shorts or grounds.
7. To check the EGT indicators.
8. To check engine thermocouples and harness on the engine with the engine removed from the aircraft.
9. To read engine rpm to an accuracy of ±0.1 percent during engine runup.
10. To use the rpm check (TAKCAL) and potentiometer in the jetcal analyzer to establish the proper relationship between exhaust gas temperature and engine speed on engine runup during tabbing. (Tabbing is the procedure followed to adjust fixed or variable exhaust gas tail cone areas during normal checks of the aircraft, approximately every 30 to 50 hours.)
11. To check aircraft fire detector, overheat detector, and wing anti-icer systems by using tempcal probes.

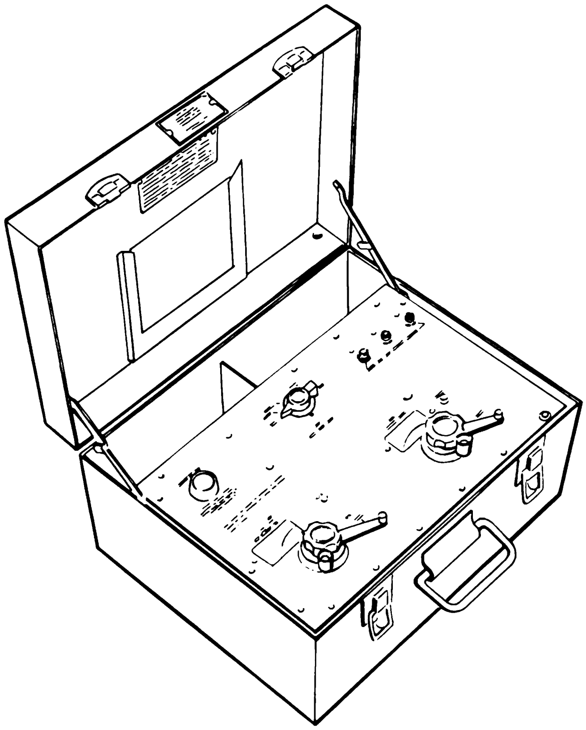
For detailed instructions in performing the above tests, refer to the Operation and Service Instruction Manual, NW 17-15A-503, for the jetcal analyzer.

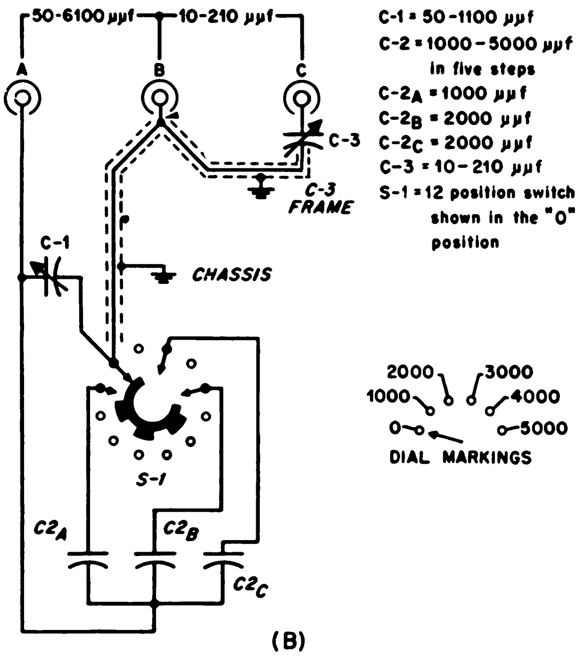
CAPACITOR FUEL QUANTITY TESTERS

Many different types of capacitor fuel quantity testers are used in naval aviation. All operate on the same basic principle, which is that of a variable capacitor. Since it is impractical to describe all of the different types of testers, only the MD-1 and MD-2 are discussed. These are the latest types and may be used to test any type capacitor fuel quantity system that is now in use on naval aircraft.

MD-1 Capacitance Tester

This tester is shown in figure 23-9 (A) and is essentially a variable capacitor with a calibrated range of 50 to 6,100 micromicrofarads ($\mu\mu f$). The tester has two variable capacitors, three fixed capacitors, a rotary wafer switch, and three mating connectors. All are enclosed in a moisture-resistant aluminum box. This box is shock mounted inside


(A)



(B)

Figure 23-9.—(A) MD-1 Capacitance Tester; (B) schematic diagram of tester.

a portable case which also contains a compartment for stowing the cables supplied with the MD-1 tester. Figure 23-9 (B) shows a schematic diagram of this tester.

The tester is used to check both the accuracy and calibration of capacitor fuel quantity systems. It is substituted for the fuel quantity tank units in the aircraft. It simulates the capacitance of a full or empty tank. This is done by setting the correct capacitance in the tester. Each tank unit or tank unit system for a particular aircraft will have a set capacitance for empty and for full. These values are given in the Maintenance Instructions Manual for the type aircraft being tested.

The testing procedure for a typical aircraft is as follows:

1. Obtain the capacitance values of the capacitor tank units from the Maintenance Instructions Manual (full and empty capacitance values).
2. Turn off all electrical power in the aircraft.
3. Disconnect the aircraft's tank unit cables from the fuel quantity amplifier.
4. Connect the MD-1 tester to the amplifier by means of cables provided in the lid of the tester.
5. Adjust the MD-1 tester to the value of capacitance for empty. This is given in the Maintenance Instructions Manual.
6. Make all proper connections and check to see that they are properly secured.
7. Energize the aircraft's fuel quantity system.
8. Allow at least 2 minutes for the fuel quantity amplifier to warm up.
9. After the fuel quantity system has warmed up, the cockpit indicator should rotate to the empty position.
10. If the fuel quantity indicator does not read empty or zero, the EMPTY adjustment screw must be turned until the indicator reads zero.
11. After the zero adjustment is made, set the added capacitance for full reading into the MD-1 tester. The value (amount) of the additional capacitance is given in the Maintenance Instructions Manual.
12. The indicator should start moving from empty to full, and stop at full.
13. If the full reading is in error, correct it by resetting the FULL adjusting screw.

14. After this adjustment has been made, check the zero adjustment again. Adjust if necessary.
15. Turn off the aircraft electrical power.
16. Disconnect the tester from the amplifier and reconnect the tank unit cables. Make sure the cables are secure.

MD-2 Capacitance Tester

This tester is shown in figure 23-10 (A). It can be used to check the electrostatic capacitance and direct-current resistance of fuel quantity gage tank units of the capacitor type. The tester has been designed primarily for field use as a troubleshooting instrument. However, it may also be used in repair and overhaul shops. The tester is designed to operate from a 115-volt, 400-cycle, single-phase power supply. The capacitance measuring circuitry employs a transformer type bridge, a high gain amplifier, and an indicator that uses a low inertia, 2-phase motor indicator. (See fig. 23-10 (B).)

The amplifier is a standard unit similar to the type used in aircraft fuel quantity systems. The insulation resistance measuring circuitry employs an electronic unit and an associated indicator of the permanent magnet moving coil type similar in circuitry to a megger. The tester is capable of measuring and automatically registering electrostatic capacitance over a range of approximately 0 to 5,000 micromicrofarads. The tester is also capable of measuring and registering insulation resistance of approximately 0.5 to 10,000 megohms.

The resistance checking section of the MD-2 tester has two purposes. It is used to check the resistance between the tank electrodes and between the tank electrodes and ground. It is also used to check the interconnecting cables for resistance and grounds.

TESTER FOR ANGLE OF ATTACK SYSTEM TYPE S3

The S3 angle of attack tester (fig. 23-11) is a portable tester, designed for use either on a bench or in the aircraft during line maintenance.

The angle of attack tester performs the following functions:

1. Permits testing system component parts before installation.

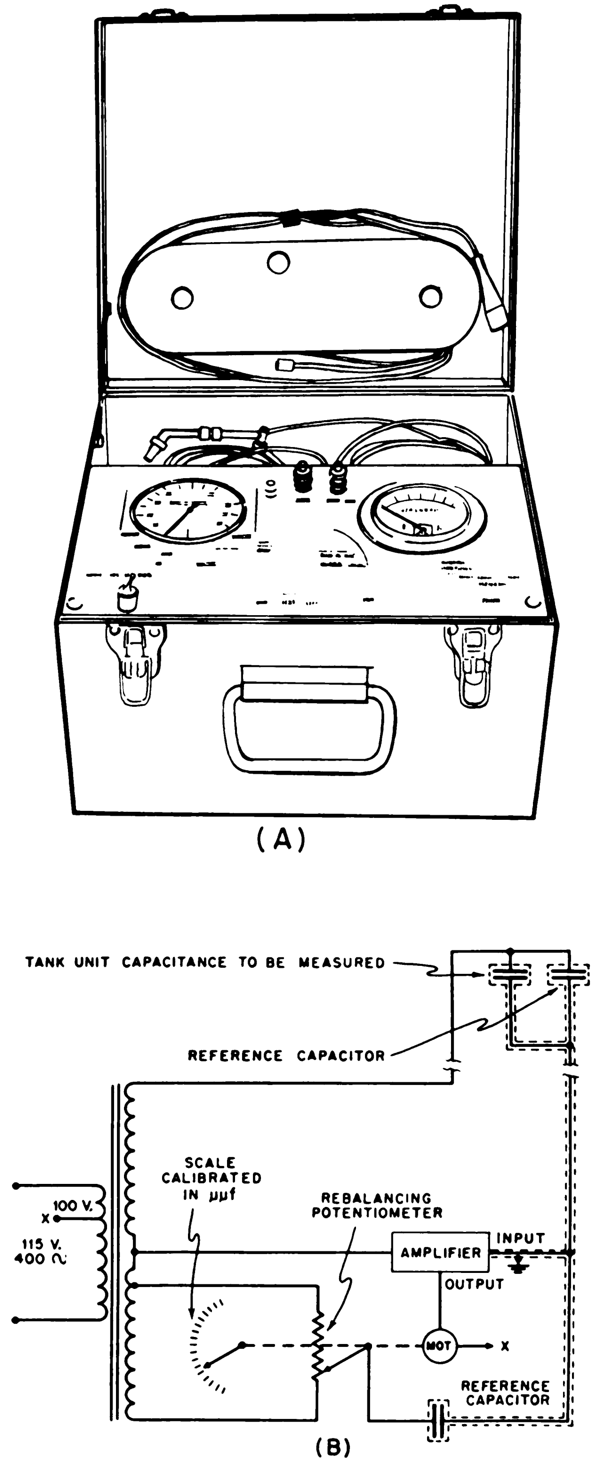


Figure 23-10.—(A) MD-2 Capacitance Tester; (B) schematic diagram of the basic capacitance measuring circuit.

2. Permits setting approach light and accessory switches at a bench.

3. Permits checking units installed in an aircraft to detect any malfunctioning unit.

4. Permits checking any single unit.

The tester unit is powered by 28 volts d.c. at 4 amperes. For the correct test procedure for a particular aircraft or system, the AE should check the applicable Maintenance Instructions Manual for that aircraft. For additional information on the operation and service of the S3 Angle of Attack Tester, refer to the Operation and Service Instruction Manual, NavAer 17-15C-503.

ADDITIONAL TEST EQUIPMENT

In addition to the test equipment already discussed, the AE is required to operate certain other test equipment. Some of these are listed below along with the basic Navy Training Course in which they are described:

Ammeter	Basic Electricity, NavPers 10086-A
Frequency meter	Basic Electricity, NavPers 10086-A
Ohmmeter.	Basic Electricity, NavPers 10086-A
Voltmeter.	Basic Electricity, NavPers 10086-A
Wattmeter.	Basic Electricity, NavPers 10086-A
Tube tester.	Basic Electronics, NavPers 10087-A

AUXILIARY POWERPLANTS

The power requirements for starting and servicing modern aircraft are very high. Even with the aircraft's batteries fully charged, their capacity is not sufficient to withstand the heavy loads of starting an aircraft.

The battery should be used for starting reciprocating engines only in extreme emergency. The Navy has spent much money on auxiliary powerplants (APP's) which are used for aircraft starting and for furnishing power for electrical circuits when performing operational checks on the ground.

There are many types of auxiliary powerplants in use. The type used by the AE depends upon the type of aircraft to be serviced. Some powerplants are designed for universal use, while some can be used only on specific aircraft.

On any of the plants described below, the a-c frequency is automatically controlled by a governor that controls the speed of the plant. The voltage is controlled by a voltage regulator. No attempt should ever be made to regulate the voltage or frequency by adjusting the hand throttle. When the plant is in use, the hand throttle should be pulled out all the way to its stop and locked in position. If the unit does not regulate to the proper speed (frequency), it must then be serviced by the APP shop.

NC-5 POWERPLANT

This ground powerplant is self-propelled and may be driven from place to place in the same manner as any other motor vehicle. (See fig. 23-12.) It has provisions for delivering three different kinds of power, each through a separate cable. This powerplant will deliver continuously a maximum of 500 amperes of d.c. at 28 volts for servicing power purposes. It will also deliver up to 1,000 amperes of d.c. at 35 volts for starting jet engines, but only for 1 minute at a time. Both servicing and starting power are taken from the same d-c generator; however, this generator will deliver only one type of power at a time.

In addition to d-c servicing and starting power, the NC-5 will deliver 208 volts or 115 volts a-c power through a 4-conductor cable. This is 30 kva, 3-phase, 400-cycle power and is used for servicing a-c equipment in the aircraft.

In the 4-conductor cable, there is a conductor for each of the three phases. The fourth conductor is referred to as "neutral." Between any two a-c phases are 208 volts. Between any one a-c phase and neutral there are 115 volts.

There are times when both servicing d.c. and starting d.c. are needed. Since both cannot be obtained from the d-c generator simultaneously, provision is made for rectifying the NC-5's a-c output into d.c. and using it for servicing power. This is the only time that servicing power is not furnished by the d-c generator.

The NC-5, being a self-propelled ground unit, should be treated with as much care as an automobile. This means that oil, water, tires, and battery are checked periodically.

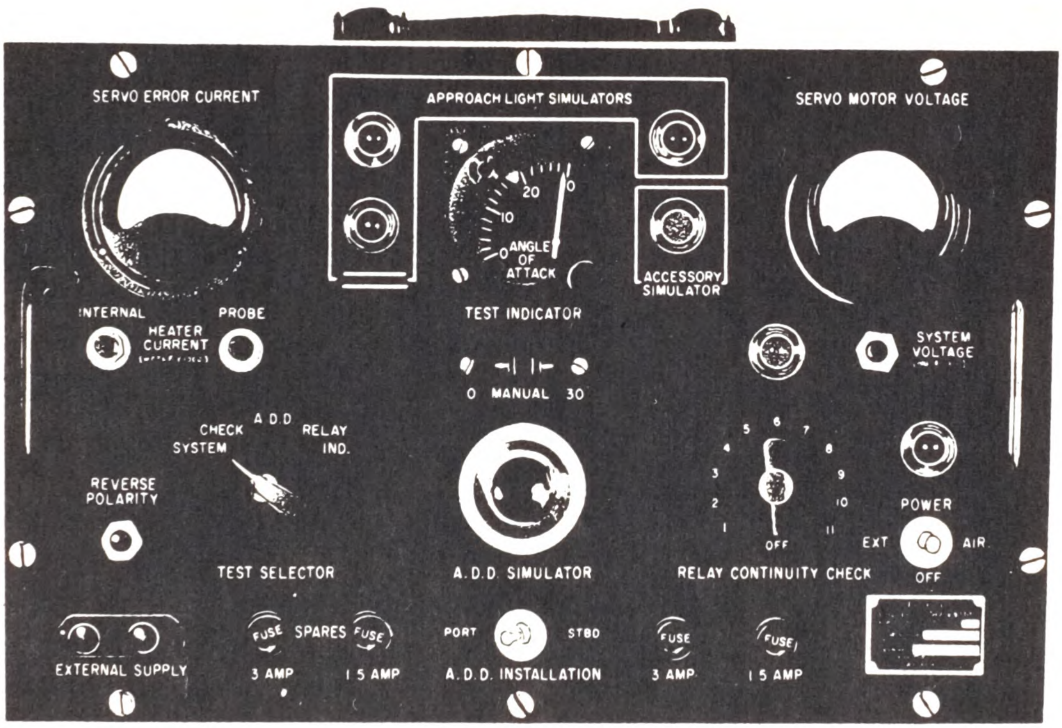


Figure 23-11.—S3 angle of attack tester.

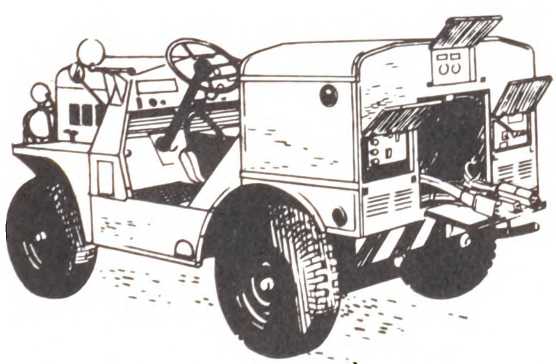


Figure 23-12.—Self-Propelled Electric Powerplant type NC-5.

The NC-5 should be operated only by a qualified and authorized operator.

NC-6 POWERPLANT

This is not a self-propelled plant; however, provisions are made for towing it. It consists of an 8-cylinder gasoline engine mounted on a 4-wheel chassis. The gasoline engine drives an a-c generator which delivers 30 kva, 208/115-volt, 400 cycle, 3-phase current through a cable identical to the one on the NC-5. It also supplies 28 volts d.c. with a rating of 200 amperes continuous duty. This is provided by a rectifier that is similar to the one in the NC-5 powerplant. When d-c power is derived from the NC-6, the a-c power capability is 20 kva.

The NC-6 is used to service equipment only; it must not be used to start jet aircraft or service any equipment that will overload it.

NC-7 POWERPLANT

The NC-7 powerplant (fig. 23-13) is powered by an 8-cylinder gasoline engine mounted on a 4-wheel trailer which is capable of being towed or moved under its own power by a self-contained propulsion unit.

CAUTION: Do not move the powerplant by means of the self-contained propulsion mechanism while supplying power to an aircraft. Under no condition is the powerplant to be used as a prime mover for towing other equipment nor should it be towed faster than 20 mph.

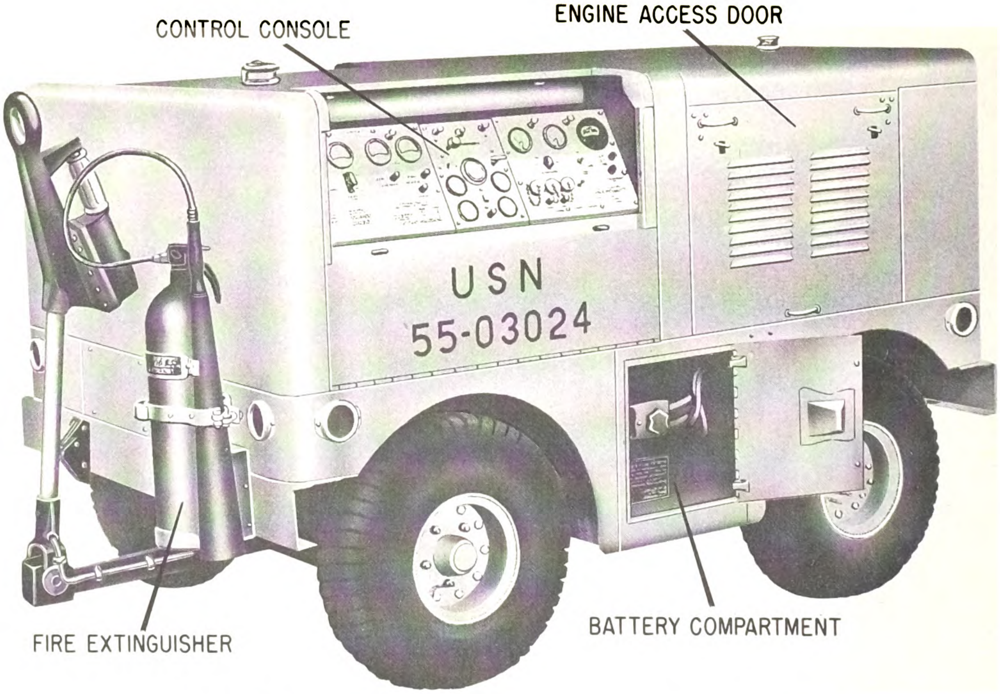


Figure 23-13.—Mobile Electric Powerplant Type NC-7.

The self-propelling feature should be used only when moving from one aircraft to another or from the line to the hangar if the distance is not too great.

The NC-7 powerplant will furnish 28 volts d.c. for starting aircraft jet engines and provides 28 volts d-c servicing, and 120/208-volt, 3-phase, 400 cycle a.c. for a-c servicing.

NC-10 AND NC-10A POWERPLANTS

The NC-10 and NC-10A powerplants are diesel engine-driven mobile powerplants, designed to supply 90 kva at 115/200 volts, 3-phase, 400 cps for servicing, starting, and maintaining helicopters and jet aircraft. A portion of the electrical power generated is rectified to supply 28 volts d.c. at 750 amperes (1,000 amperes intermittent) for aircraft starting.

The powerplant is enclosed in a steel housing, fabricated in two sections which are easily removed for servicing of the unit. Operating components are mounted on a 4-wheel trailer, which is equipped with mechanical type internal expanding front wheel brakes. The brakes may be set by a hand lever or automatically when the tow bar is in the vertical position.

Double hinged doors provide access to the control panel, starting components, and three output power cables.

The plant's electrical system is protected from overload by output circuit contactors, circuit breakers, over- and under-voltage relay, over- and under-frequency relay, thermal overload relays, and fuses.

The NC-10 powerplant was designed for use on carriers and shore stations. The NC-10A (fig. 23-14) was especially designed for Marine Corps shore duty activities. The operating features and technical data are the same for both plants, except that the NC-10A employes a self-propelled feature.

NC-12 AND NC-12A POWERPLANTS

The NC-12 and NC-12A are diesel engine-driven powerplants, designed to supply 125 kva at 115/200 volts, 3-phase, 400 cps for servicing, starting, and maintaining helicopers and jet aircraft. A portion of the electrical generated power is rectified to supply 28 volts d.c. at 750 amperes (1,000 amperes intermittent) for aircraft starting. These units utilize

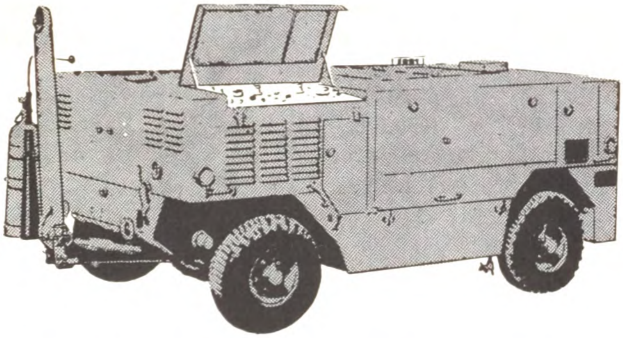


Figure 23-14.—Mobile Electric Powerplant Type NC-10A.

dual electrical power output circuits which make them capable of delivering electrical power for two P-3A aircraft.

The powerplants and components are mounted on a 4-wheel trailer, equipped with mechanical front wheel brakes which are actuated by a hand lever or the spring-loaded tow bar. These units do not come equipped with self-propelled features. The units must be towed.

The NC-12 and NC-12A are both designed the same, except the NC-12 was designed for shore duty operation and utilizes a 6-cylinder engine. The NC-12A was designed for carriers or shore-based installations and comes equipped with a V-8 series engine.

The electrical characteristics are the same for both NC-12 and NC-12A. Figure 23-15 depicts the NC-12A.

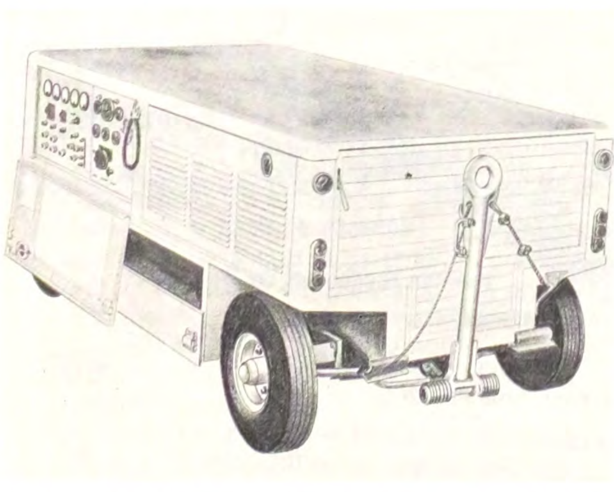


Figure 23-15.—Mobile Electric Powerplant Type NC-12A.

The AE will come in contact with many new types of powerplants such as the NC-10 series and NC-12 series, which will eventually replace the older plants such as the NC-5, NC-6, and NC-7 series.

(NOTE: Most Naval Air Facilities have training courses available to provide instruction in the use and operation of mobile powerplants.)

WAUKESHA POWER UNIT

This unit uses a 4-cylinder, 4-stroke cycle liquid-cooled engine that is mounted on a 2-wheel pushcart. The engine drives a 300-ampere, 28-volt, d-c generator. This power unit is shown in figure 23-16.

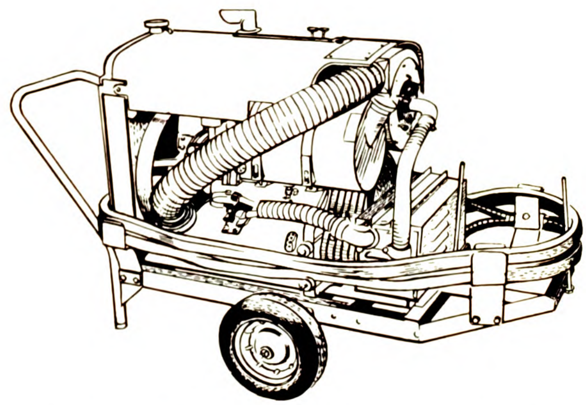


Figure 23-16.—Waukesha power unit.

The Waukesha power unit is used to start reciprocating engines and to provide d-c servicing power. The unit may be started either manually or electrically. The manual starting is accomplished by pulling a starting cable in one rapid movement. The electrical start is accomplished by placing the start switch on the control panel on START. As soon as the engine starts, release the START switch, and it will return to the OFF (center) position. When starting, open the throttle about halfway. In cold weather it may be necessary to use the choke.

Before plugging the cable of this power unit into an aircraft, be certain that all switches in the aircraft are off and that the power switch on the unit is off. After the unit is connected to the aircraft, turn on the power switch and open the throttle.

The Waukesha power unit uses a standard 24-volt, 34-ampere-hour aircraft battery to stabilize the voltage output of the generator. This battery also provides a means of electrical starting by motorizing the generator.

Before disconnecting the power unit from the aircraft, turn all switches in the aircraft and the unit's power switch off. To stop the power unit's engine, pull the throttle all the way out. Never use the choke to stop the engine unless the closed throttle method fails. The Waukesha power unit should be checked for oil, water, and battery condition periodically.

GROUND SERVICING UNIT CP 105

The AiResearch CP 105 is a gas turbine-driven power and refrigeration aircraft ground support unit furnished to the Navy in three different configurations. It is used primarily in support of the A-5A and F-4B aircraft. All three arrangements employ basically the same system, using a small gas turbine to supply air for refrigeration, main aircraft engine starting, pilot suit pressurization, and electrical power. (NOTE: Electrical power is generated by an air-driven turbine.)

The RCPP 105 (one of the three available models) is mounted in a 22-foot long aerodynamic pod for air transportation as an aircraft external store. On the A-5A, the pod is transported under the wing; and on the F-4B, it is carried under the fuselage. A cradle type towable trailer is provided for ground movement of the unit. (See fig. 23-17.)

The RCPT 105 is mounted in a self-propelled, low-silhouette (38 inches from the ground) trailer.

The tractor unit is similar to the RCPT 105 except that the turbine-driven unit is mounted on a diesel tractor.

AIRBORNE AUXILIARY POWERPLANTS

Some of the larger aircraft are equipped with small auxiliary powerplants. These may be installed at different locations on different

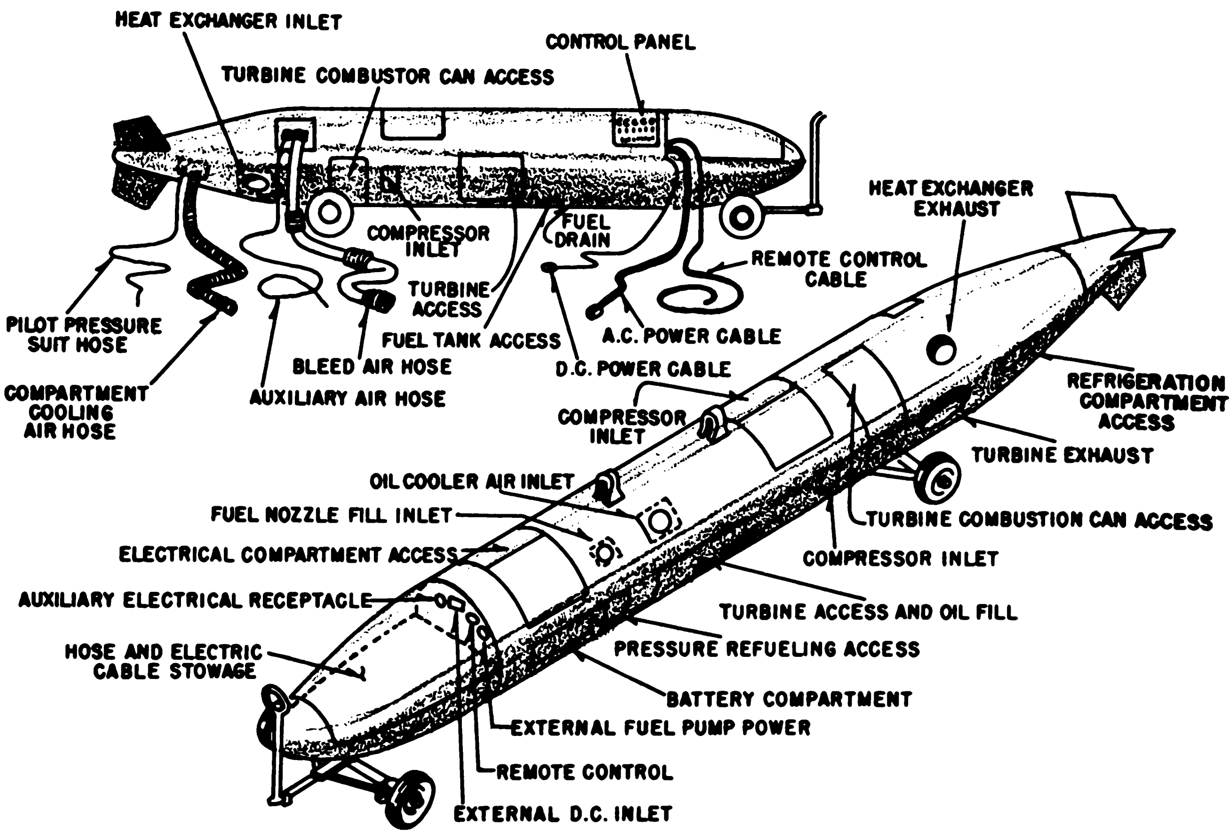


Figure 23-17.—RCPP 105 showing external connections.

aircraft. They are used to furnish electrical power when engine-driven generators are not operating or when external power is not available. Aircraft auxiliary powerplants are particularly useful on seaplanes. These aircraft are often moored to buoys for long periods of time during which mooring lights must be on and communications equipment used. The APP is utilized to furnish power since excessive battery usage must be avoided when possible.

Another particular application for the powerplants is in large land-based aircraft. Here, they are used to provide a constant voltage at a constant frequency. This is advantageous because the output of the APP is not dependent on aircraft engine rpm.

Some of these units use a gasoline engine to drive the generator, while others use a gas turbine. Figure 23-18 (A) shows a gasoline engine-driven APP; figure 23-18 (B) shows a gas turbine type.

Auxiliary powerplant logbooks must be kept on each powerplant. The operator of the powerplant is responsible for entering the operating time in the log each time the powerplant is used.

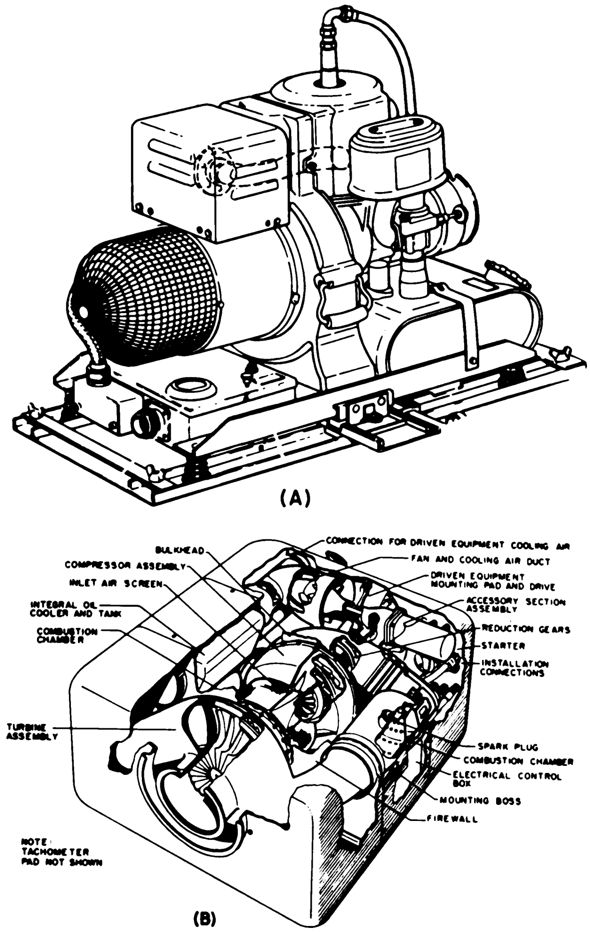


Figure 23-18.—(A) Gasoline engine-driven APP; (B) gas turbine type.

DECKEDGE POWER

The primary function of the deckedge electrical power system installed on aircraft carriers is to provide a readily accessible source of servicing and starting power to aircraft at almost all locations on the carrier's flight and hangar decks.

The 28-volt d.c. is supplied by motor-generators or rectified a.c. from remote a-c generators.

The 400-cps, 3-phase a-c servicing voltage is usually supplied by these a-c generators through stepdown transformers. Figure 23-19 shows a diagram of an electrical system which may be found on a modern carrier. The deckedge power may be supplied by service outlets at the edge of the flight deck or from recesses in the flight deck. All systems have standard remote control switches, service outlet boxes, and portable cables. Figure 23-20 shows a typical deckedge installation.

The d-c service outlet box contains two male plugs. One is rectangular in shape and the other is oval. The rectangular plug provides servicing power and the oval provides starting power for aircraft with electrical starters.

The aircraft is equipped with an oval-shaped plug for applying d-c servicing power and a rectangular-shaped 6-pin plug for applying 3-phase, 400 cps, a-c servicing power. Power is applied to the aircraft by connecting the portable cables between the deckedge and aircraft plugs. To obtain d-c servicing power, the oval end of the portable cable is connected to the oval plug in the aircraft and the opposite (rectangular) end is connected to the rectangular deckedge plug.

To obtain 3-phase, 400 cps, a-c service power, the portable a-c plug is connected to the aircraft and the opposite end to deckedge a-c service power box. The ends of the a-c portable cable are interchangeable.

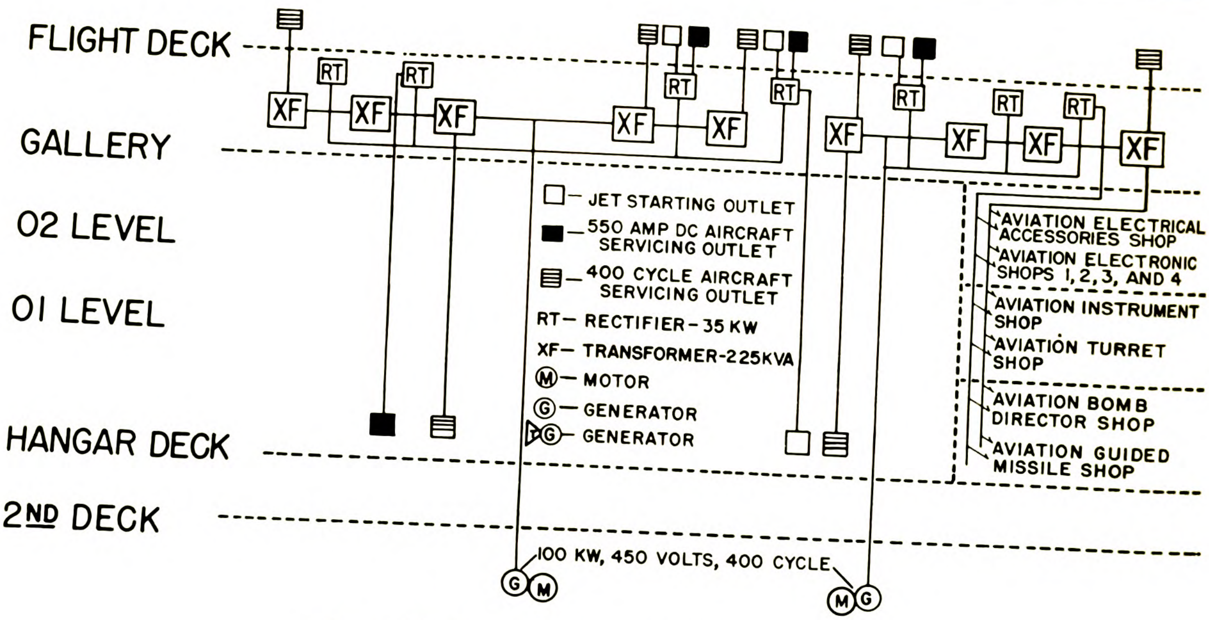


Figure 23-19.—Deckedge electrical system.

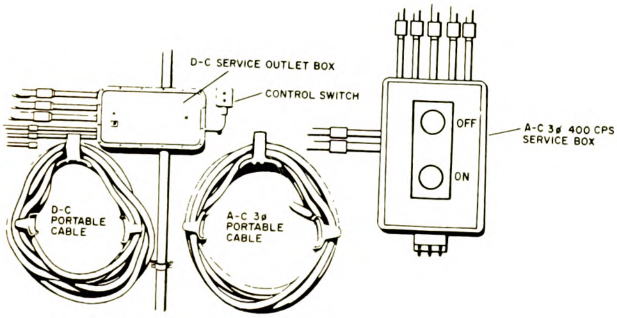


Figure 23-20.—Typical deckedge installation.

Figure 23-21 illustrates how these connections may be made. To obtain d-c servicing power to the aircraft, connect the cable from A to A'; to obtain a-c service power connect it from B to B'

The a-c service power is usually provided at the same station as the d-c power. The cable and plug are the same type as provided on the NC-5 (APP). The cable is usually permanently attached to the service outlet box. Although its plug is rectangular, there is no danger of connecting it to the d-c service power receptacle as the size and number of pins are not the same.

Care should be exercised when connecting auxiliary power cables to the aircraft. The cables are heavy, and damage to the aircraft may result if there is not sufficient slack in the cables.

AIRCRAFT ELECTRICAL AND INSTRUMENT CHECKS

PERIODIC MAINTENANCE PROGRAM

When a new aircraft model is introduced into fleet usage, the expected service life has already been determined. In order to insure safe operation throughout its service life, the aircraft is scheduled for a rework (or overhaul, depending upon the aircraft model) at

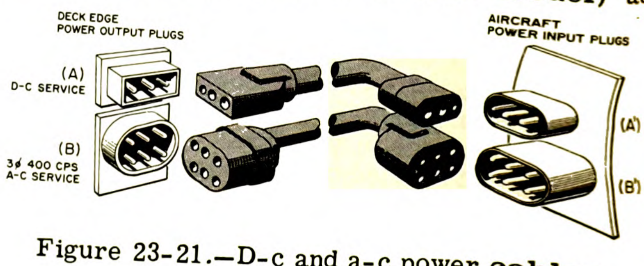


Figure 23-21.—D-c and a-c power cables and plugs.

intervals of a given number of months. In addition, thorough inspections are scheduled for the aircraft at intervals of a predetermined number of weeks. Various other inspections, varying in scope, purpose, and frequency, are performed on naval aircraft to insure that they are retained in a serviceable condition. Types of inspections which are performed by activities responsible for the maintenance of naval aircraft are as follows:

1. Acceptance Inspections. A minimum acceptance inspection consists of an inventory of installed material and loose gear, configuration verification, functional test of appropriate emergency systems, and a thorough daily inspection.

2. Daily Inspections. Daily inspections are accomplished between the last flight of the day and the next scheduled flight, if no more than 72 hours elapse between the inspection and the next scheduled flight. If more than 72 hours elapse between the inspection and the next flight, the inspection must be repeated. Basically, this inspection is a combination of requirements for checking equipment that requires a daily verification of satisfactory functioning, plus requirements that prescribe searching for and correction of relatively minor problems to preclude their progression to a state that would require major maintenance to remedy. Other items which require inspection at more frequent intervals than prescribed for calandar inspections are also included on the daily inspection and are accomplished along with the daily inspection on the day they become due.

3. Preflight Inspections. The preflight inspection consists of checking the aircraft for flight preparedness by performing visual examinations and operational tests to discover defects and maladjustment which, if not corrected, would cause accidents or aborted missions. The preflight inspection also includes a check to determine that the aircraft has been properly serviced for the next flight.

4. Calendar Inspections. A calendar inspection is a thorough and searching examination of the aircraft and is conducted at predetermined calendar periods of time (13 weeks, 15 weeks, 17 weeks, etc., as assigned by higher authority). All aircraft are subject to only two of four types of calendar inspections, depending upon the program under which they are being maintained.

a. Calendar Intermediate Inspections. The intermediate inspection is a limited overall examination of the condition of the aircraft. The inspection includes certain requirements that are also applicable to the daily or preflight inspections and requirements that must be applied at periods occurring more frequently than major inspections.

b. Calendar Major Inspections. The major inspection is a thorough and searching inspection of the aircraft. This inspection includes certain requirements that are also applicable to the daily, preflight, and intermediate inspections. Both intermediate and major inspections are applicable to all aircraft not being maintained under the Periodic Maintenance Requirements Program.

c. Calendar Periodic Inspections. There are two inspections included in the term calendar periodic inspection. Each of these inspections is a thorough and searching examination of the aircraft and consists of requirements due at every inspection, plus additional requirements that are due at less frequent intervals. For identification purposes the inspections are designated as odd calendar and even calendar inspections. The less frequently scheduled requirements are divided equally between the odd and even inspections, when practicable, to provide a balanced calendar inspection workload.

5. Special Inspections. A special inspection is an inspection which either does not have a prescribed interval for inspection and depends upon the occurrence of certain circumstances or conditions, or has an interval other than the standard inspection cycle.

6. Pilot's Weekly Aircraft Inspections. At present there are no Navy-wide rules for the accomplishment of this inspection. This inspection is accomplished as directed by the controlling custodian and the individual commanding officer.

Minimum scheduled (calendar) maintenance and inspection requirements are established and published by direction of the Chief of the Bureau of Naval Weapons either in Handbooks of Inspection Requirements (HIR) or in a Periodic Maintenance Requirements Manual (PMRM). Daily and preflight requirements are common to both of these publications. The HIR governs

the intermediate and major inspections, and the PMRM governs the odd and even inspections.

Periodic Maintenance Requirements Manual

The latest approach to aircraft inspections is the Periodic Maintenance Requirements Program. In this program, inspection and maintenance requirements are promulgated in a Periodic Maintenance Requirements Manual. This manual establishes what must be inspected and what conditions are sought. It does not contain instructions for repair, adjustment, or other means of discrepancy correction; nor does it provide instructions for troubleshooting to determine the cause of malfunctions. Maintenance personnel must refer to the other pertinent publications and directives for assembly, disassembly, check, test, and repair procedures.

The Periodic Maintenance Requirements Manual is part of the set of manuals available for each aircraft model. The planned maintenance requirements promulgated by the manual are considered to be the minimum necessary under any conditions to insure timely discovery and correction of latent defects. Compliance with the manual is mandatory.

Revisions to the manual are published at periodic intervals to add, delete, revise, or change requirements. Such revisions are based on factual data accumulated as a result of maintenance experience with the aircraft.

Maintenance Requirements Cards

The prescribed maintenance requirements as promulgated in the Periodic Maintenance Requirements Manual are presented to the maintenance man in the form of Maintenance Requirements Cards (MRC). Usually three decks of cards are provided for each aircraft model being maintained under this inspection system. These cards consist of one deck each for preflight, daily, and calendar inspections. All the minimum requirements for the accomplishment of any particular periodic maintenance task, or portion thereof, are contained in a set of these cards.

The work plan, or order of performing the inspection, is prearranged in two manners. The preflight and daily work is performed item by item in numerical order arranged on consecutively numbered cards. The calendar inspection work is controlled by the order of arrangement of the items on the cards, and in addition, requires a sequence chart for scheduling the MRC's. Different sequence charts are used for odd and even inspections; hence, the calendar cards are not necessarily scheduled in numerical card number sequence.

A master file copy of current MRC's must be maintained within the maintenance department. This master file copy reflects all revisions to the published card sets, plus any locally added requirements. Local periodic maintenance requirements, not covered by the published MRC sets, can be added in two ways: (1) By adding the requirement to existing cards, or (2) by using blank cards provided for this purpose.

When an aircraft is undergoing an inspection, the cards are provided to the maintenance man one or more at a time and in the specified order. He does not certify the completion of the work on the cards; therefore, the cards are used as many times as their condition permits.

Prior to issuance of a deck of cards to the check coordinator, each card should be checked against the master file deck to insure that they are complete and current. (This is a function of the quality control division.)

The front side of each basic card (fig. 23-22 (A)) begins a new maintenance requirement. The back side of the card (fig. 23-22 (B)) carries the same number as the front. In case the text and illustrations cannot be contained on the front and back of the basic card, a point-numbered card may be used. For example, Card 223 may be continued on Card 223-1. Point-numbered cards are not listed on the sequence charts.

Sequence Charts and Equipment

In order to provide a guide for the preparation of the actual calendar maintenance work schedule and a means of controlling the assignment of work and personnel, calendar sequence charts have been developed and provided as an integral part of the Periodic Maintenance Program. These charts indicate what maintenance requirements cards are to be complied with, the number and specialty of the personnel required, the times during which the separate jobs are scheduled for accomplishment, and the "power on" or "power off" condition required during the work. The sequence charts have been planned to efficiently integrate all required periodic

CARD 159	TIME 00:25	RTG. AE NO. 1	CALENDAR		ELEC PWR N/A; HYD PWR N/A
MAN MIN	WORK AREA	MOS. 6631 NO. 1	PUBLICATION NUMBER NAVWEPS 01-245FDA-6-3	CARD SET DATE 1 August 1964	CHANGED
02	1	1. Static pressure ports for obstructions and cleanliness (Radome).			
02	1	2. Flight Director Signal Adapter (AN/AJB-3A) for dents, corrosion, and security.			
01	1	3. Frequency and load control box for evidence of overheating. (Do not reconnect.) (Radome)			
01	1	4. "G" Limit Accelerometer for corrosion, dents, and broken case or connector.			
04	1	5. Electrical connector plugs at all components and bulkheads for looseness, cracks, corroded outer shell, frayed wires and loose or broken ties and lockwire.			
04	1	6. All visible wire bundles for chafing, pinching, loose or broken ties and anchor clips, loose or corroded terminals, damage plastic covering and obstructed drain holes.			
02	1	7. Cabin emergency vent valve assembly for corrosion, loose or distorted control linkage, loose duct connection; dump valve for loose connecting lines and obstructed ambient vent; microswitch for security (Door 5R).			

(A)

MAN MIN	WORK AREA	CARD 159.1	PUBLICATION NUMBER NAVWEPS 01-245FDA-6-3	ELEC PWR N/A; HYD PWR N/A
01	1	8. Cabin air outlet valve for cracks, loose duct connections, loose or distorted linkages and corrosion (Door 5R).		
02	1	9. Right, left and essential autotransformers for evidence of overheating. (Door 124)		
01	1	10. Right generator control panel for evidence of overheating. (Door 122R)		
02	1	11. Right Static Exciter Regulator for evidence of overheating. (Right forward missile cavity)		
01	1	12. Left Generator Control Panel for evidence of overheating. (Door 122L)		
02	1	13. Left Static Exciter Regulator for evidence of overheating. (Left forward missile cavity)		

(B)

Figure 23-22.—Maintenance requirements card. (A) Front; (B) back.

maintenance work so as to effectively reduce the total out-of-service time required for the complete periodic maintenance job. A complete set of calendar sequence charts consists of a minimum of three sheets. Sheet 1 is used with the odd calendar inspection, sheet 2 is used with the even calendar inspection; sheet 3 concerns shop work on the powerplant. Figure 23-23 shows a portion of a sequence control chart for the F-4B odd-numbered calendar inspection.

Daily Scheduled Maintenance Planning Form, NavWeps 4730/3

This form is used to plan and project the daily scheduled maintenance requirements for each individual aircraft between calendar periodic maintenance periods. It aids in assuring that all required maintenance is scheduled on time and enables supervisory personnel to plan workloads accordingly. The form provides a number of spaces for each day in which to enter MRC numbers that require compliance on a basis other than every day (10 day, 30 day, "conditional," etc.). It also provides a means for writing in all other scheduled maintenance due during the calendar maintenance period designated for the aircraft. This form should be filled in to cover the entire interval between inspections. This should be accomplished while the aircraft is undergoing calendar periodic maintenance so that all scheduled maintenance for the subsequent operating period will be known at the time the aircraft is returned to an operational status.

Preflight/Daily/Inflight Maintenance Record, NavWeps Form 4730/4

This record form (fig. 23-24) is used in conjunction with the Daily Scheduled Maintenance Planning Form to enable scheduled work to be assigned in a preplanned manner between calendar inspections. This form controls and assigns responsibilities for preflight and daily scheduled maintenance including the special and conditional work that may be required. These forms can be prepared daily or made up in numbers sufficient to cover a desired period of time. Local conditions provide the best indication of the method to be used.

In the illustration it should be noted that all the preflight and daily items are on one side of the card and the special and conditional items are on the other side. The certification on the front indicates that items on both sides of the card have been accomplished.

Calendar Periodic Maintenance Record, NavWeps Form 4730/5

This form (fig. 23-25) provides a record, establishes credit, and fixes responsibility for scheduled work performed during calendar periodic maintenance. In addition, it provides a means for cross-checking the discrepancies reported on the Calendar Discrepancy and Parts Replacement Records completed for the particular calendar maintenance period. Each person performing calendar maintenance completes this form incident to the work assigned to him by the supervisor. More than one form is required if the number of MRC's assigned exceeds the spaces provided on the form. Forms are returned to the supervisor as the work indicated thereon is completed, or at the end of each day, and reissued the next day for work that is not completed. All entries indicating work to be accomplished are entered by the person assigning the work. All other entries are completed by the person performing the work.

HANDBOOK OF INSPECTION REQUIREMENTS

Prior to the introduction of the Periodic Maintenance Requirements Program, inspection and maintenance requirements were promulgated for all aircraft in Handbooks of Inspection Requirements (HIR's). With the introduction of the new program, the handbook system was retained in effect for most aircraft being inspected and maintained thereunder. With minor exceptions the new system is being gradually phased in by applying it to all new production aircraft as they are introduced to fleet service. At present, steps are being taken to bring all older model aircraft under the Periodic Maintenance Program. This is a gradual program and therefore, the HIR is discussed briefly in the following paragraphs.

To promote standard maintenance procedures and to enhance the probability of aircraft receiving similar maintenance throughout the Navy, it is essential that no deletions be made from checksheets without BuWeps approval. However, activities may add inspection

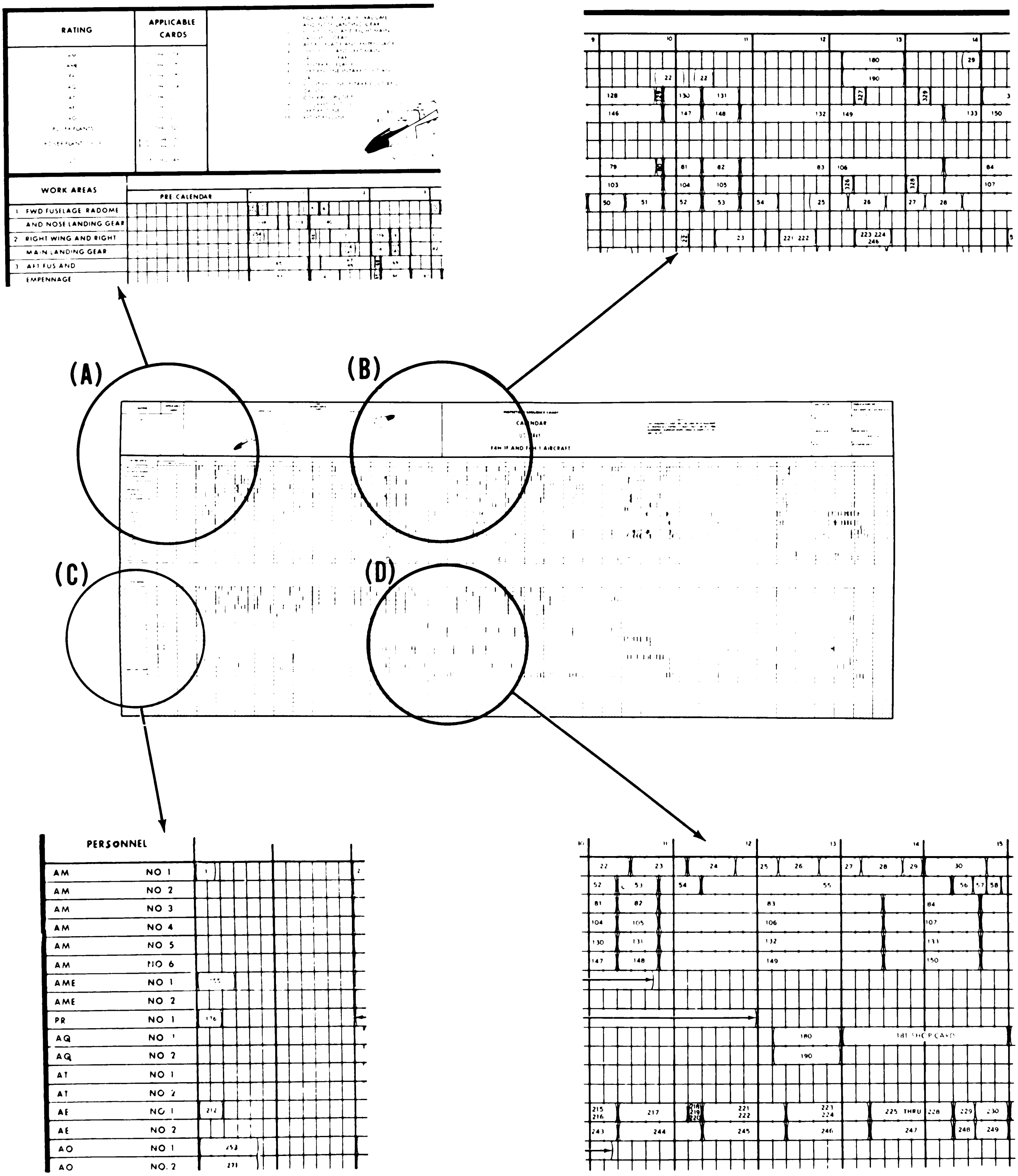
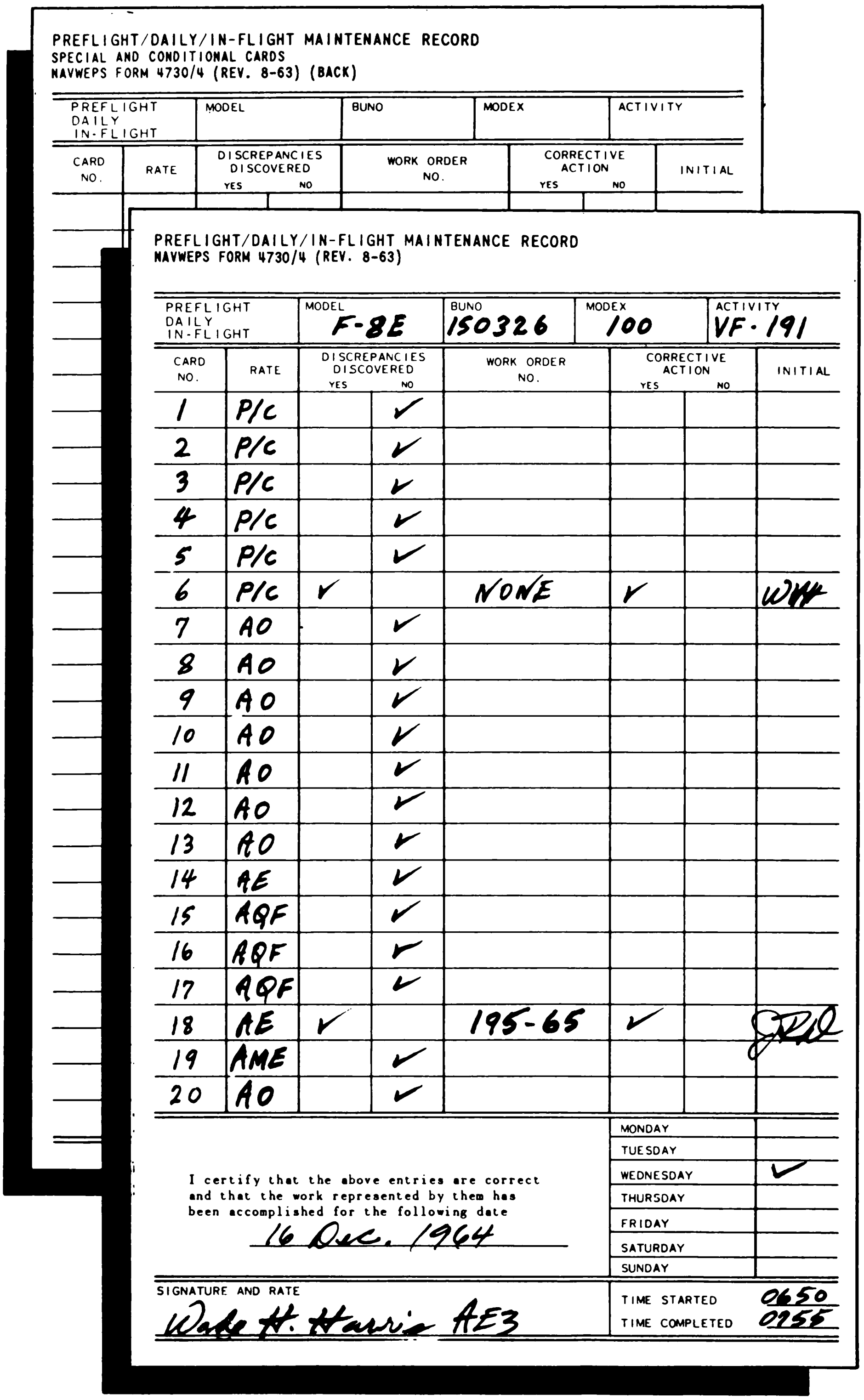


Figure 23-23.—Sequence control chart.



PREFLIGHT/DAILY/IN-FLIGHT MAINTENANCE RECORD
SPECIAL AND CONDITIONAL CARDS
NAVWEPS FORM 4730/4 (REV. 8-63) (BACK)

PREFLIGHT DAILY IN-FLIGHT	MODEL	BUNO	MODEX	ACTIVITY

CARD NO.	RATE	DISCREPANCIES DISCOVERED YES	NO	WORK ORDER NO.	CORRECTIVE ACTION YES	NO	INITIAL

PREFLIGHT/DAILY/IN-FLIGHT MAINTENANCE RECORD
NAVWEPS FORM 4730/4 (REV. 8-63)

PREFLIGHT DAILY IN-FLIGHT	MODEL	BUNO	MODEX	ACTIVITY
	F-8E	150326	100	VF-191

CARD NO.	RATE	DISCREPANCIES DISCOVERED YES	NO	WORK ORDER NO.	CORRECTIVE ACTION YES	NO	INITIAL
1	P/C		✓				
2	P/C		✓				
3	P/C		✓				
4	P/C		✓				
5	P/C		✓				
6	P/C	✓		NONE	✓		WHH
7	AO		✓				
8	AO		✓				
9	AO		✓				
10	AO		✓				
11	AO		✓				
12	AO		✓				
13	AO		✓				
14	AE		✓				
15	AQF		✓				
16	AQF		✓				
17	AQF		✓				
18	AE	✓		195-65	✓		[illegible]
19	AME		✓				
20	AO		✓				

I certify that the above entries are correct and that the work represented by them has been accomplished for the following date

16 Dec. 1964

MONDAY	
TUESDAY	
WEDNESDAY	✓
THURSDAY	
FRIDAY	
SATURDAY	
SUNDAY	

SIGNATURE AND RATE
Wade H. Harris AE3

TIME STARTED	0650
TIME COMPLETED	0955

Figure 23-24.—Preflight/Daily/Inflight Maintenance Record.

CALENDAR PERIODIC MAINTENANCE RECORD NAVWEPS FORM 4730/5	CALENDAR NUMBER EVEN	DATE ISSUED 5/16/65

CARD SET DATE	RATE / NUMBER	MODEL	BUNO	MODEX	ACTIVITY
1 MAY 1965	RATE AE NUMBER 2	F-4B	151411	502	VF193

CARD NO.	MAN MIN.	DATE COMPLETED	ITEMS COMPLETED	DISCREPANCIES DISCOVERED ITEM #	NO. #
328	15.0	5/16/65	all	none	
329	20.0	5/16/65	all	none	
330	5.0	5/16/65	all	none	
331	42.0	5/16/65	all	none	

I certify that the above entries are correct and the work represented has been accomplished.	SIGNATURE AND RATE OF PERSON PERFORMING WORK W. A. Smith AE 3

Figure 23-25.—Calendar Periodic Maintenance Record.

items to meet unusual or special requirements due to local climatic or operational conditions.

The checksheet portion of the handbook, which consists of the intermediate and major inspection checksheets, is divided into the various systems of the aircraft and contains the checksheet for each system. The sections with which the AE is mainly concerned are the instrument and electrical system sheets (and sometimes the utility sheets). He goes through each item until he has completed the intermediate or major inspection. As a general rule, checksheets are posted on or near the aircraft to be used as a guide and a record of progress.

At the beginning of each system division there are three blank forms, Periodic Inspection Order and Report, Discrepancies Found and Corrected Report, and Parts Replacement Report. The Periodic Inspection Order and Report (fig. 23-26 (A)) is to be partly filled in by the maintenance officer before it is issued for a periodic inspection. He will list the additional work which is to be performed during the periodic inspection interval. Examples of additional work are the Replacement Schedule items listed in Part 1 of the handbook, flight discrepancies, squadron work orders, configuration checks, incorporation of changes or bulletins, etc. Items in the "Work Completed By" column are signed off by the person completing the work, not necessarily a member of the inspection crew.

The Discrepancies Found and Corrected Report (fig. 23-27 (A)) is used to indicate to the maintenance officer what discrepancy was found, who discovered the discrepancy, and who accomplished the necessary work. The sheet should be used as conscientiously as possible, bearing in mind that an accurate history of component discrepancies is important to the complete history of an aircraft. Every man should be on the alert for defects of components that are not necessarily his primary responsibility. It is important that such defects be written on the Discrepancies Found and Corrected Report of the proper system. If an electrician finds a hydraulic defect, it should be written on the hydraulic system Discrepancies Found and Corrected Report. When items

NAVWEPS 01-85SA-7 **Part 2**

Bureau of Naval Weapons
Periodic Inspection Order and Report

S-2A, C-1A Aircraft
Instruments System

INTERMEDIATE AND MAJOR INSPECTION CHECK SHEET

SIDE NO.	BUNO.	INSPECTION INTERVAL (hours or calendar time)	NAME (Intermediate or Major)
15	141336	120	MAJOR
DATE COMPLETION REQUIRED	ESTIMATED MAN-HOURS	INSPECTOR	CREWLEADER
21 FEB. 1965	Int 1.0 Maj 1.7	D. E. Parker	J. W. Browning
Perform the following additional items of inspection and work.		PERSON AUTHORIZING CHECK (Signature)	
		W. G. Bolton LT	

DESCRIPTION	WORK COMPLETED BY (Signature)	INSPECTED BY (Signature)
Lubricate in accordance with aircraft Maintenance Instructions Manual. ASC 334	W.N. Kaste	D.E. Parker

(A)

COMPLETION REPORT

The inspections and work required have been accomplished. All items which were not satisfactory on initial inspection have been reported under the Discrepancy Report on the reverse side of this sheet. The discrepancies have been corrected and all items are now satisfactory. Parts used have been reported on the Parts Replacement Report on the reverse side of this sheet. No parts other than those listed have been replaced.

DATE	TIME CHECK STARTED	TIME COMPLETED	MAN-HOURS USED
21 FEB. 1965	0800, 19 FEB. 1965	1400, 21 FEB. 1965	5

SIGNATURES W.N. Kaste
C. Britton

J. W. Browning
(Crew Leader)

D. E. Parker
(Inspector)

(B)

Figure 23-26.—(A) Periodic Inspection Order and Report; (B) Completion Report.

PART 2 NAVWEPS 01-85SA-7

Bureau of Naval Weapons

S-2A/C-1A Aircraft
Instruments System

INTERMEDIATE AND MAJOR INSPECTION CHECK SHEET

DISCREPANCIES FOUND AND CORRECTED REPORT

ITEM NO.	DISCREPANCY	FOUND BY (Name)	CORRECTED BY (Name)	INSPECTED BY (Name)
1	ELEVATOR TRIM TAB INDICATOR BROKEN	J. Nunn	R.T. Shirly	W.N. Koste

(A)

PARTS REPLACEMENT REPORT

ASO STOCK NUMBER	NOMENCLATURE	SERIAL NUMBER		REASON REPLACED AND REPLACED BY
		OLD	NEW	
R6610-514-5253--V170	INDICATOR, ELEVATOR TRIM TAB	36536	48012	BROKEN CASE R.T. Shirly

(B)

Figure 23-27.—(A) Discrepancies Found and Corrected Report; (B) Parts Replacement Report.

are written on this form, the inspection is not complete until the defects are corrected and signed off by the correcting mechanic. All repairs accomplished, even though not listed on the Periodic Inspection Order and Report or Inspection Check List, should be briefly described in the Discrepancies Found and Corrected Report. The Parts Replacement Report (fig. 23-27 (B)) lists every part that is replaced during this inspection interval.

NOTE: For this purpose, a part is defined as any part or component which, by nature of its use or location, may be of value in regard to a complete maintenance history of the aircraft, and/or requires a logbook entry or submission of an unsatisfactory report.

TROUBLESHOOTING

Much of the AE's time is spent troubleshooting the equipment in his squadron's aircraft.

This is reason enough for him to become a proficient troubleshooter. The AE's job is to maintain a great number of components and systems, many of which are quite complex, and which might seem at a glance beyond his ability to maintain. However, the most complex job will usually become much simpler if it is first broken up into successive steps. Any maintenance job which the AE is required to do should be performed in the following order:

1. Analyze the trouble.
2. Detect and isolate the fault.
3. Correct the fault and test your work.

ANALYSIS OF TROUBLE

The AE cannot hope to work effectively on a system or component which he does not understand. The first step in any job is to understand what a system is supposed to do, then how it does this. Once these questions are answered, the very nature of the trouble itself will usually suggest an answer as to what is wrong. An understanding of a particular system may best be obtained by referring to the Maintenance Instructions Manuals. These manuals answer any questions the AE might ask about a particular aircraft. They are among his most useful aids in analyzing a trouble before starting work. These manuals explain what an entire system does, what each component does, the location of the components, and much other useful information. Once the AE has used a manual and analyzed a particular system, he will find that an idea of what is wrong will usually present itself almost as soon as he hears a description of the trouble.

Two steps in analyzing trouble are (1) determining what a system is supposed to do, and (2) determining the most likely cause for the trouble.

DETECTION OF FAULTS

Visible condition of system components is usually the first thing to check in any process of troubleshooting. If certain parts are obviously not in proper condition, correct these faults before going any further. Such conditions include equipment being burned, loose from mounting, disconnected, dented, or any other obviously improper condition. If there is nothing visibly out of order, the next step is to check the power supply.

If there is nothing visibly wrong with an electric component, the next logical step is to see if it is receiving power. Again, there is need of the Maintenance Instructions Manual. It will indicate just which pin in a certain connector is used to bring the power to the connector. The manual will also show exactly which circuit breakers must be closed and which switches to use for testing. They are shown on the electrical schematics in Section X of the Maintenance Instructions Manual. If there is power to the component and it still does not work, then the obvious fault is with the component itself.

If there is no power reaching the component, assume temporarily that it is all right, and start checking the power supply. The best place to start checking a power supply is usually at the bus which supplies it. Consult the manual and locate successive points along a wire at which to make power checks. The first and most important step is to check the condition of fuses and circuit breakers. Their condition will determine the next move. If a circuit breaker is tripped or a fuse blown, power should immediately be turned off because this indicates a circuit malfunction and power should not be reapplied until the malfunction is corrected. If a short, ground, or overload condition is not indicated, continue to take power readings at the checkpoints. The most common faults which interrupt power through a circuit are broken wiring, loose terminal or plug connections, faulty relays, and faulty switches. Be alert for these conditions when checking the successive points along a circuit. If, as mentioned earlier, there is evidence of a short circuit or overload, secure the power and prepare to start continuity and resistance checks.

Continuity and Resistance Checks

The process of fault detection often leads beyond visual inspection and power checks. The voltmeter will indicate if a power circuit is delivering power to the proper place, but will rarely identify the nature of a trouble when one exists. A better instrument for identifying the nature of a trouble is the ohmmeter. With the ohmmeter, the exact nature of the trouble can be determined. When properly used, it will indicate opens, shorts, grounds, or wrong values of resistance. By constant reference

to a schematic, any circuit or component can be traced, piece by piece and wire by wire, until the trouble is completely isolated. Wiring, control switches, relays, and other such isolated components are relatively easy to check since their individual circuitry is usually simple. It is quite a different story, however, when checking a complex component with internal wiring and parts forming a maze of branches and interconnected paths.

When checking a particular component, refer to the Operation and Service Instruction Manual. This manual contains information on one specific piece of equipment and lists all the proper resistance readings between certain connector pins.

In addition to the various types of testing meters, there are various bench-test installations. These are used when a component is removed from the aircraft and taken into the shop for operational tests. They are designed to test each part of some certain system, such as a remote compass system. In a typical installation, there is a complete and fully operational system with the components grouped closely together. This enables the troubleshooter to remove any unit and replace it with one he wants to test. In this manner, the unit's performance can be checked under conditions that are almost identical to those in the aircraft.

This method of trouble detection is especially useful when the nature of the trouble is not completely clear; that is, when the unit is functioning to some extent, but does not measure up to minimum standards. These test installations are highly specialized and will only perform specific tests on specific components. Much of the AE's troubleshooting is performed with a meter and a schematic, and the use of his technical knowledge.

Nonelectric Components

The information that has been given so far has dealt only with fault detection in systems using electric power. There is, however, a group of systems and components which do not use electricity. This group includes such items as mechanical instruments, direct reading gages, and mechanisms closely associated with electrical equipment. Such mechanisms are switch actuators, mounting assemblies, mechanical linkages, and any type of hardware that is part of an electrical system. This equipment is not checked with a voltohmmeter, but the three basic rules for troubleshooting remain the same--analyze, detect, and correct. Once the fault has been located, the next step is to correct it.

CORRECTION OF FAULTS

Detailed instruction on how to correct any specific fault is beyond the scope of this chapter. Such instruction would involve writing a training course on the one subject. Many faults may occur, and for each fault a corrective job must be performed. There are general rules which apply to practically all such corrective work. In many cases, the correction of a fault involves more time and labor than detecting it. For this reason it is a good idea to keep these general rules in mind so that the time and workload can be minimized.

First, study the job and think through each step to be performed. Form a plan of attack and at the same time decide which tools are needed. In addition to handtools, equipment such as extension lights and cooling blowers should be considered. They are well worth the extra time it takes to obtain them, especially on a prolonged job. The Maintenance Instructions Manual lists special tools needed, and also describes the best way to gain access to some certain units or area; that is, some component may be mounted at an obscure location in the aircraft so that it may be approached only through a certain inspection plate or from a certain direction. Another source of valuable information is someone who has performed a particular job before. He can usually offer some very good pointers.

The troubleshooter should also plan methods of dealing with special conditions which will be encountered during a job. Some of these are excessive hydraulic oil drainage from disconnected lines, dangling and unprotected power cables, high-pressure air lines, and the handling of very heavy components such as starters and generators.

Gas or liquid lines may be drained or bled off, and heavy objects should be handled with special care. (NOTE: Only Aviation Structural Mechanics will work on oxygen lines.) If exposed power cables are unavoidably left loose, some means should be used to avoid their shorting out. This may be accomplished by covering them with a temporary insulating

shield and by placing a warning sign on the main power switch in the cockpit and on the external power receptacle. Another very good precautionary measure is to disconnect the aircraft battery. In this case, a sign should be placed in the cockpit stating that the battery is disconnected. All of the safety measures mentioned here should be completed before work is started.

The procedures used in actually doing the work are determined by the nature of the work. The job can be classed as either repair or replacement. The quality of any job performed is determined by how well all the smaller operations are performed. This refers to such operations as soldering, replacement of connecting devices, safety wiring, and use of tools.

Good techniques should be learned and practiced. An excellent way to learn them is by doing the work under the supervision of an experienced man. Installation Practices for Aircraft Electric and Electronic Wiring, NavAer 01-1A-505, is an excellent reference. It sets forth the accepted way of performing a great number of practical operations, and is well illustrated.

REPLACEMENTS

In many cases the replacement of a part is obviously the correct thing to do, as in the case of burned-out fuses, lamps, and resistors, or broken instruments. However, replacement of parts should never be used as a method of troubleshooting. Each year, thousands of dollars worth of instruments and "blackboxes" are returned to overhaul activities with labels stating that they are faulty. When these are tested by the overhaul activity, many are found to be in working order.

This practice is wasteful and very expensive, and reflects badly on the quality of a squadron's maintenance program. This refers, of course, to replacing parts on suspicion, without establishing proof that they are actually faulty. In the same category of poor maintenance is the replacement of an entire unit when only a small component is at fault. A typical example of such a case is the replacement of an entire compass amplifier when there is only a single faulty vacuum tube or fuse. The troubleshooter should remember that he is often working with equipment that is both expensive and in short supply. For this reason, decisions to replace equipment should be made only after thorough tests have shown it to be faulty.

The procedures to follow in the replacement of equipment are included under the headings removal, installation, and testing. Each will be discussed.

Removal

Removal of equipment should be done in such a way that further damage is not caused to it or to nearby structure. Particular attention should be given to keeping small parts from being lost or misplaced. They may be easily replaceable with new ones, but small items that are lost in the aircraft will constitute a very real hazard if they are not found. This refers to nuts, bolts, washers, small tools, and safety-wire clippings.

If the new part cannot be installed immediately, remove all tools and parts from the aircraft during the waiting period. They are too easily forgotten if left in the aircraft. Once the part that is to be replaced is removed from the aircraft, notice should be placed in the cockpit. This is to prevent such occurrences as fuel pumps being turned on when fuel lines are opened or power being applied to loose cables. The serial numbers of all parts replaced on an aircraft are recorded in the aircraft's logbook. These serial numbers should be noted before the new part is installed and the old part turned in.

Installation

Many of the rules for removal apply also to installation. However, there are a few things which apply almost exclusively to installing new equipment. Some units are put into special condition for shipping. This is something to watch for, because it often means that sealing plugs, locking devices, and other special equipment must be removed from the component before installing it. If adjustments are to be made on new equipment, investigate the possibility of doing it before the installation is completed.

For example, the matching of a position transmitter to the position indicator in the cockpit can often be easily accomplished with only the electric wiring connected to the actuator. After calibration, mechanical mounting is completed. Again, the best guide for making adjustments to any system is the Maintenance Instructions Manual. In the final installation, particular care should be taken in connection with two major points.—(1) mounting hardware

should be used in every place required and properly tightened, and (2) cables or lines should be connected to the proper points.

Testing

The entire process of detecting and correcting a fault will mean nothing unless it is determined that the system operates properly. To determine this, the final step of the job is to test the equipment. This test is usually of an operational nature. Where possible, simply operate the new component to see that it is doing its job properly and within the minimum time requirement. When a final check has shown that the job is completed, notify the division petty officer. It is important to pass this word quickly, because the aircraft is officially ''down'' until all paperwork is signed and the proper people are notified.

QUICK ENGINE CHANGE

The quick engine change is referred to as a QEC. The QEC facilitates the removal and installation of all types of aircraft engines. The QEC unit includes the engine with necessary fuel and oil lines, electric harnesses, and other engine equipment with the exception of standard accessories such as fuel pumps, starters, generators, propellers. These units provide engines which are ready for installation when needed. Accessories not included in the QEC unit must be removed from the old engine and installed on the new.

ELECTRICIAN'S RESPONSIBILITIES

The AE's responsibility on a QEC is to check all electrical units prior to installation. This includes components, wiring, and instrument tubing.

Components

Visually check all components. Test all components with appropriate test equipment. Install accessories such as generators, starters, pressure switches, actuators, and solenoids. Safety wire all components according to approved standards.

Wiring and Tubing

Visually check all wiring and instrument tubing for proper installation and marking. Check to see that all accessories are properly connected. Make sure that electrical wiring and instrument tubing are routed and secured in accordance with existing specifications.

TYPES OF QEC

There are basically two types of engines on Navy aircraft; namely, jet engines and reciprocating engines. Therefore, it could be said that there are two types of QEC. However, the AE's responsibilities already discussed are applicable to both. Some differences are obvious, such as the fact that reciprocating engines (on multiengine aircraft) have propeller feathering circuits, while jets do not.

Always refer to the Maintenance Instructions Manual for the particular type of aircraft when an engine is to be installed.

BUILDUP

Change Kits

QEC kits are drawn from supply for engine buildup on the basis of the number of aircraft supported by an activity.

Under some conditions, it is necessary to change the aircraft engine alone and transfer the necessary parts and accessories to the new engine. Lack of available parts and accessories is the main reason for using this procedure. However, under no circumstances should components from a quick change kit be used for replacement of overaged components or accessories or for the incorporation of service changes on an engine not in buildup. Occasionally, due to the small number of operating hours on some particular component, it may not be advisable to change it. In this case, the new component is returned to supply and an appropriate entry is made on the accessory and component service record.

Installations

The AE assigned to an engine buildup is under the direct supervision of the senior member of the buildup crew (usually an AD). The sequence of installations is determined by this senior petty officer. This tends to speed the buildup process.

Directives and Changes

As stated previously, the AE must comply with all current directives and changes in each stage of installation. If in doubt about directives or changes, do not hesitate to consult with a senior petty officer.

Inspection and Test

No engine buildup is complete until a careful inspection and test have been performed on the new engine. After the runup of the engine, all accessories should be inspected for leaks and security of mounting.

CORROSION CONTROL

The AE will find that aircraft corrosion control in the Navy has become an all-hands evolution. In his everyday work he can improve the quality of corrosion control. Careless handling of tools and equipment, scuffing of feet, etc., can result in damage to protected finishes, leaving areas unprotected from corrosion. Even a fingerprint on an unprotected surface will cause corrosion and metal etching. It behooves the AE to learn what corrosion is and how it reacts.

DANGERS OF CORROSION

Current aircraft are dependent on the operational and structural soundness of the metals, basically high strength aluminum alloys, which make up the largest percentage of its thousands of parts. With higher strength demands being made of aircraft metals and the closer tolerances of flight safety demanded, these aircraft would rapidly become inoperative without regular anticorrosion maintenance.

Corrosion can cause eventual structural failure if left unchecked. The appearance of the corrosion varies with the metal. On aluminum alloys and magnesium it appears as surface pitting and etching, often combined with a gray or white powdery deposit. On copper and copper alloys the corrosion forms a greenish film; on steel a reddish rust. When the gray, white, green, or reddish deposits are removed, each of the surfaces may appear etched and pitted, depending upon the length of exposure and severity of attack. If these surface pits are not too deep, they may not significantly alter the strength or ductility of the metal; however, the pits may become sites for crack development on parts which are critical in fatigue. Some type of corrosion can travel beneath surface coatings and can spread until they perforate the coating or the part fails.

CORROSIVE ATTACK

There are two general classifications of corrosion which cover most of the specific forms. These are direct chemical attack and electrochemical attack. In both types of corrosion the metal is converted into a metallic compound such as an oxide, hydroxide, or sulfate. This is somewhat the reverse of the process by which a metal is refined from its ore. The corrosion process always involves two simultaneous changes—the metal that is attacked or oxidized suffers what may be called anodic change, and the corrosive agent is reduced and may be considered as undergoing cathodic change. The individual characteristics of direct chemical attack and electrochemical attack are further discussed.

Direct Chemical Attack

Direct chemical attack or pure chemical corrosion is an attack resulting from a direct exposure of a bare surface to caustic liquid or gaseous agents. Unlike electrochemical attack where the anodic and cathodic changes may be taking place a measurable distance apart, these changes in direct chemical attack are occurring simultaneously at the same point.

The most common agents causing direct chemical attack on naval aircraft are spilled battery acid or sulfur trioxide fumes from batteries; residual flux deposits resulting from inadequately cleaned welded, brazed, or soldered joints; or entrapped caustic cleaning solutions. Spilled acid from batteries as a cause of direct chemical attack is becoming less of a problem with the advent of aircraft utilizing fixed frequency alternating current and external starting units, thereby eliminating the need for a battery installation. Some aircraft use nickel-cadmium batteries which are usually sealed units. The use of these sealed units lessen the hazards of acid spillage and battery fumes.

Many types of fluxes used in brazing, soldering, and welding are corrosive, and they chemically attack the metals or alloys with which they are used. Therefore, it is important in most

cases that residual flux be removed from the metal surface immediately after the joining operation. Flux residues are hygroscopic in nature; that is, they are capable of absorbing moisture and unless carefully removed, tend to cause an attack resulting in severe pitting. Rosin-cored solder used in electrical and electronic soldering is an exception; its flux need not be removed except as required for potting (moistureproofing) connectors.

Caustic cleaning solutions in concentrated form should be kept tightly capped and away from aircraft. Some cleaning solutions used in corrosion removal are potentially corrosive agents themselves, and particular attention should be directed toward their complete removal after use on aircraft. Where entrapment of the solution is likely to occur, a noncorrosive cleaning agent should be selected even though less efficient in its action than others.

Electrochemical Attack

An electrochemical attack may be likened chemically to the electrolytic reaction which takes place in electroplating, anodizing, or in a dry cell battery. The reaction in this corrosive attack requires a medium, usually water, which is capable of conducting a tiny current of electricity. When a metal comes in contact with a corrosive agent and is also connected by a liquid or gaseous path through which electrons may flow, corrosion begins as the metal decays by oxidation. During the attack, the corrosive agent becomes cathodic and is destroyed (neutralized). The metal is said to become anodic during the oxidizing (corrosion) process. Different areas of the same metal surface have varying levels of electrical potential and if connected by a conductor, such as salt water, will set up a series of corrosion cells and corrosion will commence. Figure 23-28 illustrates a simple corrosion cell on the surface of a metal block.

All metals are electrically active and are said to have potential. Precipitated metallic constituents in an alloy retain their potential. Exposure of the alloy surface to a conductive, corrosive medium causes the more active metal to become anodic and the less active metal to become cathodic, thereby commencing the process of corrosion. The greater the difference in electrical potential between the two metals, the greater will be the severity of a corrosive attack if power conditions are allowed to develop.

The trigger for these corrosive electrolytic reactions consists of a corrosive medium and a conductor. If by regular cleaning and surface refinishing, the medium is removed and the minute electrical circuit prevented, corrosion cannot occur, and therein lies the basis for effective corrosion control.

Climate

The environmental conditions under which an aircraft is maintained and operated greatly affect corrosion characteristics. In a predominantly marine environment with exposure to sea water and salt, moisture-laden air is considerably more detrimental to an aircraft than would be the case if all operations were conducted in a hot, dry climate.

Temperature considerations are important in that the speed of electrochemical attack is increased in a hot, moist climate and is retarded under hot, dry conditions. The corrosion control program must be geared to local service conditions and include provisions to adjust for seasonal changes.

PREVENTIVE MAINTENANCE

Consistent preventive maintenance is the most practical method of controlling metal corrosion. Maintenance such as cleaning and painting will show great savings in labor and materials by eliminating costly repairs and replacements required when corrosion has been permitted to go unarrested.

The corrosion prevented program can be adjusted to meet the severe environment of shipboard operations or relaxed when the aircraft returns to the more favorable environment of an inland base.

CLEANING

Cleaning of aircraft and equipment involves the removal of oil, grease, dirt, engine residues, and other undesirable foreign materials that adhere to their surfaces. To effectively remove these undesirable materials, certain cleaning agents such as soaps, solvents, emulsion compounds, and chemicals are employed.

Suitable equipment should be used and the correct method and sequence of procedure in applying the cleaning agents should be followed. The accepted safety regulations and health precautions should be followed in the use and handling of the various cleaning compounds.

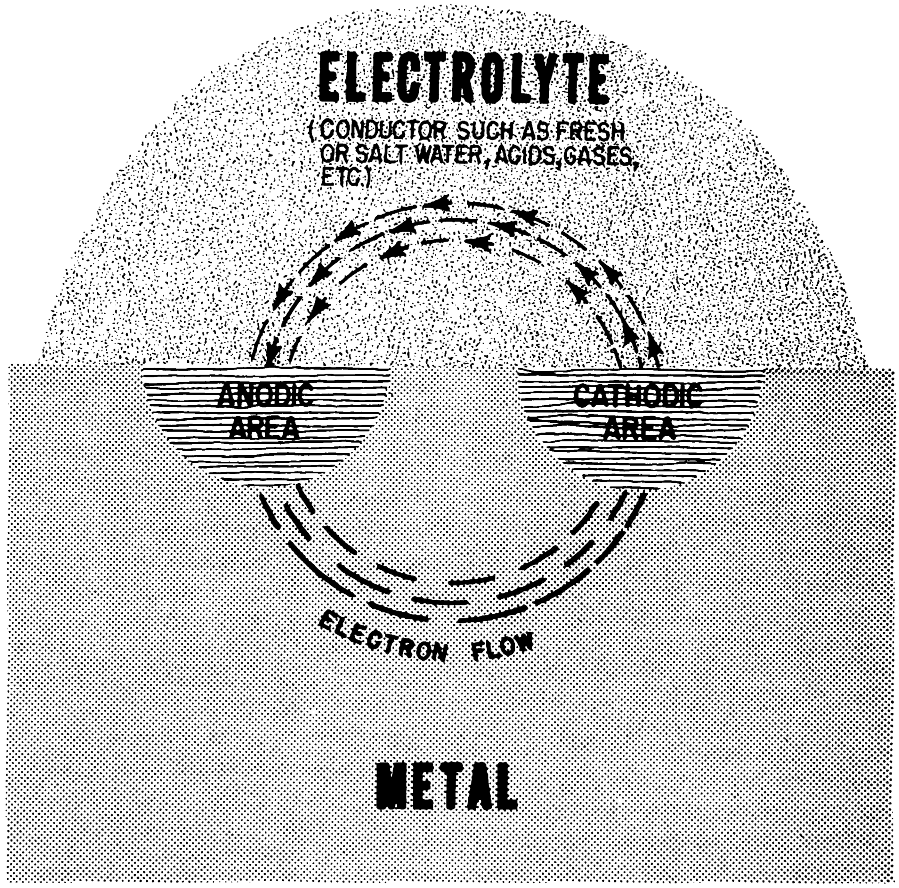


Figure 23-28.—Simplified corrosion cell.

The condition of the aircraft (that is, if covered with heavy soils and film or if only lightly soiled) should be considered when choosing a cleaning agent and method of application. Other factors that have a bearing on the choice of cleaning materials are the type and surfaces to be cleaned, such as painted or unpainted surfaces; the interior or exterior of an aircraft; and component parts and gear; for example, electronic equipment, rubber acrylics, etc.

A clean aircraft helps considerably to minimize the effects of corrosion, not only when in storage but also when in active duty.

CORROSION PRONE AREAS

Discussed briefly in this section are most of the trouble areas common to all aircraft. However, this coverage is not necessarily complete and may be amplified and expanded to cover the special characteristics of the particular aircraft model involved by referring to the Corrosion Control section of the applicable Maintenance Instructions Manual.

Exhaust Trial Areas

Both jet and reciprocating engine exhaust deposits are very corrosive and give particual trouble where gaps, seams, hinges, and fairings are located down the exhaust path and where deposits may be trapped and not reached by normal cleaning methods. Special attention should be paid to areas around rivet heads and in skin crevices. Fairings and access plates in the exhaust areas should be removed for inspection. Exhaust deposit buildup in remote areas such as the empennage surfaces should not be overlooked. Buildup in these areas is slower and sometimes completely absent but has become a problem on some currently operating aircraft.

JATO Rocket and Gun Blast Areas

These areas should be watched for corrosion and carefully cleaned after firing operations. In addition to inspection of gaps, seams, fairings, and rivets for corrosive deposits, the paint finishes in these areas are often blistered by heat or blasted away by high velocity gases, spent shell casings, or solid particles.

Gun compartment venting systems, spent ammunition collection chutes, and missile exhaust paths are additional areas in which corrosion may be accelerated as a result of firing operations. Gun bay areas should be kept sealed to prevent their becoming water traps particularly during foul weather at sea.

Battery Compartment and Battery Vent Openings

Despite improvements in protective paint finishes and in methods of sealing and venting, battery compartments continue to be corrosion problem areas. Fumes from overheated electrolyte are difficult to contain and will spread to adjacent cavities and cause a rapid, corrosive attack on all unprotective metal surfaces. Battery vent openings on the aircraft skin should be included in the battery compartment inspection and maintenance procedure. Regular cleaning and neutralization of acid deposits with sodium bicarbonate solution will minimize corrosion from this cause.

Bilge Areas

These are natural sumps for waste hydraulic fluids, water, dirt, and odds and ends of debris. Residual oil quite often masks small quantities of water which settle to the bottom and set up a hidden chemical cell. Seaplane and amphibious aircraft bilge areas are protected by small bags of potassium dichromate inhibitor suspended near the low point in each bilge compartments. These crystals dissolve in any waste water and tend to inhibit the attack on exposed metal surfaces.

Inspection procedures should include replacement of these bags when most of the chemical has been dissolved. Particular attention must be paid to bilge areas located under galleys and lavatories and to personnel relief and waste disposal vents or openings on the aircraft exteriors. Human waste products are very corrosive to the common aircraft metals. Clean these areas frequently and keep the paint touched up.

Wheel Well and Landing Gears

This area probably receives more punishment due to mud, water, salt, gravel, and other flying debris than any other area on the aircraft. There is additional harmful exposure due to salt water and salt spray when the aircraft is parked aboard ship. Owing to the many complicated shapes, assemblies, and fittings, complete area paint film coverage is difficult to attain. A partially applied preservative tends to mask corrosion rather than prevent it. Because of heat generated by braking action, preservatives cannot be used on some main landing gear wheels. During inspection of this area, pay particular attention to the following trouble spots:

1. Magnesium wheels, especially around boltheads, lugs, and wheel web areas, particularly for the presence of entrapped water or its effects.
2. Exposed rigid tubing, especially at "B" nuts and ferrules, under clamps, and tubing identification tapes.
3. Exposed position indicator switches and other electrical equipment.
4. Crevices between stiffeners, ribs, and lower skin surfaces which are typical water and debris traps.

Piano Type Hinges

Piano type hinges are prime spots for corrosion due to the dissimilar metal contact between the steel pin and aluminum hinge tangs. They are also natural traps for dirt, salt, and moisture. Inspection of hinges should include lubrication and actuation through several cycles to insure complete lubricant penetration. A water displacing penetrating preservative should be applied prior to lubrication in order to displace any water or salt solutions.

MATERIALS USED

Electrical equipment is usually sprayed during manufacture with a protective coating that seals out moisture, thus preventing corrosion and fungus growth. When repairing this equipment, it is sometimes necessary to remove the protective coating by scraping or by the use of solvent cleaners.

In general, solvent cleaners used in aircraft should have a flashpoint of not less than 40.6° C (105° F) if explosionproofing of equipment and other special precautions are to be adhered to. Chlorinated solvents of all types meet the nonflammable requirements but are toxic, and safety precautions must be observed in their use. The use of carbon tetrachloride is specifically prohibited. Stoddard solvent (P-S-661B) flashes slightly above 40.6° C and can be used to remove greases, oils, and light soils. Safety solvent, Trichloroethane (methyl chloroform), is used for general cleaning and grease removal. It is nonflammable under ordinary circumstances, and is used as a replacement for carbon tetrachloride. The use and safety precautions necessary when using chlorinated solvents must be observed. Prolonged use can sometimes cause dermatitis.

After making circuit repairs, the protective coating should be replaced. Rosin fluxes form coatings on solder connections that prevent oxidation during and after the soldering process, thus providing one form of replacement.

General-purpose sealants (when properly used under operating conditions) can materially reduce required maintenance at a later date. Dissimilar metal insulation should be restored and maintained on outer surfaces of first line fighters, using proprietary sealing compound EC-1293. Integral fuel tank sealant is used in most other insulating applications. If adherence is difficult and an improved seal is needed in crevices, a preliminary application of topcoat sealant material, Specification MIL-S-4383, will give better results than sealants alone. A nondrying, pliable sealant, Specification MIL-S-7124, is available for effective sealing around frequently removed access doors and panels.

General-purpose neoprene-to-metal cements are available for resecuring black synthetic weatherstripping. Resecuring should be initiated when the stripping starts to come loose, not after it falls off. Proprietary epoxy filleting material, such as a two-part mixture of EC-1751 and EC-1752, is particularly useful in filling dents and nicks in airfoils and in emergency repairing of damage to honeycomb structures. These two-part materials are mixed 50-50 just before use and only in amounts required for the specific repair. Similar materials under EC-1614A and EC-1614B form a clear structural filler which can be used for field repairs to reinforced plastic components.

Extensive resealing operations for entire assemblies, units, or groups are beyond the scope of this discussion. For further information see Corrosion Control for Aircraft, NavWeps 01-1A-509, and Preservation of Naval Aircraft, NavWeps 15-01-500.

CHAPTER 24

PUBLICATIONS, RECORDS, AND REPORTS

PUBLICATIONS

Naval aeronautic publications are important sources of information for guiding personnel of the naval aeronautic organization. Generally, these publications fall into two broad groups—those dealing with operational and administrative matters, and those dealing with technical and material matters. Since the Aviation Electrician's Mate (AE) is primarily concerned with the care and maintenance of aeronautic equipment, most of the discussion of this chapter is devoted to publications of a technical and material nature.

Aeronautic publications dealing primarily with the technical operation and maintenance of aircraft and related equipment within the Naval Establishment emanate from BuWeps and are issued by the authority of CNO. Publications concerned mainly with the training of flight personnel and air operations emanate from the office of the CNO (Air). Publications and data pertaining to naval aviation emanating from both the office of CNO and BuWeps are normallv distributed by the U. S. Naval Air Technical Services Facility, Philadelphia, Pennsylvania.

Technical aeronautic information is issued in manual publication and letter publication form. Each is discussed separately.

TECHNICAL MANUALS

The basic sources of technical aeronautic information are the technical manuals (formerly called handbooks) issued by BuWeps. Letter publications usually supplement the information contained in aeronautic technical manuals. These manuals and letter publications are listed in NavSandA 2002, Section VIII.

Code numbers assigned to technical manuals consist of a prefix and a number series of three or four parts. The prefix may consist of the letters NavAer, AN, TO, or CO. NavAer, usually shortened to NA, indicates that the publication was originated by BuWeps. (NOTE: the prefix NavWeps, abbreviated to NW, will replace NavAer as new publications are printed.)

The prefix AN was previously assigned for technical manuals used jointly by the Navy and the Air Force; they were prepared to coordinate military specifications. This prefix, while no longer assigned for new material, will remain in effect for existing assignments.

TO is the prefix assigned to technical manuals originated by the Air Force.

CO was previously used to designate a technical manual with a Confidential security classification. This prefix, while no longer assigned for new material, will remain in effect for existing assignments or until superseded by a later assignment.

The parts which make up the remaining portions of the number (following the prefix) indicate the following:

Part I consists of numbers to identify the general subject classification with the basic subject to which they pertain. These numbers usually have two digits; however, when an additional classification breakdown is necessary, part I consists of two digits followed by a letter. An example of this is found in the 02 (powerplants) series. A typical entry in this series has the number 02B immediately following the prefix NW. In this example, the B identifies the powerplant as a jet propulsion type.

Table 24-1 lists the general subject categories and their numerical equivalents. In some instances, it should be noted that an equipment category has more than one numerical equivalent. In the case of electronics, which carries the codes 08 and 16, the equipment category is in the process of subdivision or change.

Table 24-1.—Subject categories and code numbers for aeronautic manuals.

General	00
Allowance lists	00-35Q
Training publications (aviation).	00-80
Aircraft	01
Powerplants	02
Accessories	03
Hardware and rubber	04
Instruments	05
Fuels, lubricants, and gases.	06
Dopes and paints	07
Ground servicing and automotive equipment.	08-20, 14 & 19
Photography	10
Armament	11
Fuel and oil handling equipment.	12
Parachute and personal equipment.	13
Standard preservation and packaging instructions.	15
Electronics	08 & 16
Machinery, tools, and test equipment.	17 & 18
Descriptive data for aviation support equipment.	20
Chemical equipment	24 & 39
Instructional equipment and training aids.	09 & 28
Meteorology (aerology)	50
Ships installations	51

Part II of the publication consists of numbers, or numbers and letters, and indicates the specific class, group, type, or model and manufacturer of the equipment. The subject breakdowns are listed at the beginning of each separate major division within NavSandA 2002, Section VIII.

Part III consists of a number or numbers which designate a specific manual. For airframes and engines this part designates a specific type of manual. For other types of equipment this part is assigned in numerical sequence and has no reference to the type of manual.

Part IV consists of a number indicating the section number; this applies only to certain types of manuals, such as Maintenance Instructions Manuals for aircraft.

To illustrate the decoding of a complete publication number, let us examine the number NW 01-60ABA-2-9.

1. NW (NavWeps) indicates that the manual is a BuWeps publication.
2. The number 01 indicates that the publication is an aircraft manual. (See table 24-1.)
3. The number 60 indicates that the aircraft was manufactured by North American Aviation, Incorporated.
4. The letters ABA indicate that the manual applies to the A-5A aircraft.
5. The number 2 indicates that the technical manual is a Maintenance Instructions Manual.
6. The number 9 indicates that this is section 9, which in this case is the instruments and related systems section.

Publication numbers are important because they provide positive identification for reference, ordering, and filing. All BuWeps aeronautic manual publications are listed by number in the NavSandA 2002, Section VIII, which is discussed in more detail later in this chapter.

LETTER PUBLICATIONS

BuWeps letter publications fall into two classes—those of a general nature, and those which concern specific aeronautic equipment. The NavSandA 2002, Section VIII, together with its latest cumulative supplement, provides a checkoff list for all current technical aeronautic letter publications.

Aviation Circular Letters, Technical Orders, and Technical Notes are no longer being issued; however, some of those previously issued are still in effect. Those still in effect are listed in the current issue of NavSandA 2002, Section VIII.

Circular Letters contain information and instructions concerning policy, administration, and air operations. Such directives are now being issued in the form of instructions and notices.

Technical Orders and Technical Notes contain information and instructions concerning operation and maintenance of aircraft and aeronautic equipment. Such directives are now being issued principally in the form of manual revisions, bulletins, or changes.

BuWeps technical letter publications concerning specific items of naval aeronautic equipment are issued as Changes or Bulletins. They are numbered consecutively for each item or type of equipment covered; for example, S-2D Change No. 1, 2, 3, and so forth.

Changes contain instructions calling for some change or modification to specific aeronautic equipment. Bulletins are of an informative (rather than "action") nature but may, however, require some action. The following is a list of some specific letter publications currently being issued:

Accessories Bulletins.
Aircraft Armament Bulletins.
Aircraft Bulletins (Specific).
Aircraft Service Changes (Specific).
Aircraft Carrier Bulletins.
Aircraft Launching Bulletins.
Aircraft Instrument Bulletins.
Arresting Gear Bulletins.
Arresting Gear Changes.
Auxiliary Powerplant Bulletins.
Electronic Material Bulletins.
Electronic Material Changes.
Emergency Runway Arresting Gear Bulletins
Engine Bulletins (Specific).
Gas Turbine Compressor Bulletins.
General Engine Bulletins (Reciprocating Engines).
General Gas Turbine Engine Bulletins (Turbojet Engines).
General Helicopter Component Bulletins.
General Propeller Bulletins.
Helicopter Component Bulletins (Specific).
Pneumatic Starting System Bulletins.
Propeller Bulletins (Specific).

PUBLICATIONS LISTS AND INDEXES

Aeronautic publications originated by BuWeps and distributed by the Naval Air Technical Services Facility are covered by separate lists and indexes.

These stock lists are prepared by the Forms and Publications Supply Office, Byron, Georgia, and distributed to the mailing list maintained by the:

Naval Air Technical Services
Facility (MR),
700 Robbins Ave.,
Philadelphia, Pa. 19111

The publications index, as discussed in this section, is composed of the following separate lists and indexes: Navy Stock List of Forms and Publications, NavSandA 2002, Section VIII, Parts C and D; and Naval Aeronautic Publications Index, NavWeps 00-500A, B, and C. These lists and indexes provide the AE with a complete listing of all available aeronautical publications distributed by BuWeps. Within the different sections of the index, the AE will find numerical listings as well as cross-reference indexes. Supplements are published to keep the index current.

NavSandA 2002, Section VIII, Parts C and D

Part C of this stock list contains a numerical listing, by code number, of available aeronautic technical manual type publications. In addition to the code number, the publication title, security classification, and date of issue or date of latest revision are given. The instructions for using the stock list include an explanation of the code number system used to identify the manuals by subject group. Also included in this section is information on ordering and methods of procurement of publications. Another section of the stock list is devoted to a cross-reference index of Air Force, NavShips, and NavOrd publication numbers to the NavWeps publication numbers.

Part D of the stock list contains a listing of the letter type technical directives. These are grouped by subject matter and, in addition to the same information that is listed for manuals in part C, an effective date is included if applicable.

Parts C and D are distributed semiannually—in September and March. A supplement to these stock lists is issued monthly. This supplement is cumulative, so the preceding supplements may be destroyed upon receipt of the latest issue. Included in the supplements are lists of new manuals and letter type publications, lists of canceled publications, lists of interim revisions issued, and special notices and corrections to the basic stock list.

NavWeps 00-500A

Naval Aeronautic Publications Index (NAPI), NavWeps 00-500A, Equipment Applicability List, contains a listing of aircraft components and related equipment (by model, type, and part number) in alphabetical and numerical sequence, with the applicable publications shown in appropriate columns. This index includes both manual type publications and letter type directives. The index includes an explanation of the numbering and grouping system used for both types of publications.

The equipment applicability list is issued twice annually—in March and September.

Monthly cumulative supplements are issued to provide a listing of new publications distributed during the interval between reissues of the index.

NavWeps 00-500B

Naval Aeronautic Publications Index, NavWeps 00-500B, Aircraft Application List, contains a listing of aeronautic technical publications with respect to their applicability to a specific aircraft. For example, under the heading S-2D, manual type publications pertaining to the S-2D aircraft and any pieces of equipment installed in the S-2D aircraft are listed numerically.

NavWeps 00-500B does not list any letter publications. It lists technical manuals dealing with electronics, armament, instruments, accessories, powerplants, aircraft, and certain general publications. The manuals listed in this index are identified by publication code number only. For titles or other information on specific publications, refer to NavSandA 2002, Section VIII, Part C.

NavWeps 00-500B is also issued and distributed twice annually—in March and September.

NavWeps 00-500C

NavWeps 00-500C, Directive Application List, contains a listing of BuWeps technical directives with respect to their applicability to an aircraft.

NavWeps 00-500C is published twice annually, in January and July. At this time (1964) it is not anticipated that supplements to this publication will be issued.

MAINTENANCE INSTRUCTIONS MANUALS

Maintenance Instructions Manuals (formerly called Handbooks of Maintenance Instructions) provide information concerning the location, function, operation, removal, installation, testing, adjusting, and troubleshooting of components. Maintenance methods recommended are concerned with procedures such as those which can be performed by an operating squadron.

Before attempting any new task on an aircraft, such as removing, replacing and adjusting a horizontal stabilizer actuator, the Maintenance Instructions Manual for that particular aircraft should be consulted. By proper use of this manual, possible damage can be prevented and much time may be saved.

EQUIPMENT MANUALS

BuWeps prepares Operation and Service Instruction Manuals (formerly called Handbook of Operating Instructions and Handbook of Service Instructions) for various electrical equipments which require such instructions; Aircraft Technical Manuals meet this requirement in many cases. The Operation and Service Instruction Manuals are sometimes combined in one manual; however, they are often issued as two separate manuals. Operation Instruction Manuals cover the operation of a complete system such as the operation of an automatic flight stabilization system. Service Instruction Manuals for entire systems include only limited information about any particular component included in a system. For detailed information dealing only with one component of a system, the Service Instruction Manual for that particular component must be consulted.

For some electrical components of a system, as many as four manuals may be prepared when necessary. These are the Operation and Service Instruction Manuals, the Overhaul Instruction Manual (formerly called Handbook of Overhaul Instructions), and the Illustrated Parts Breakdown. These manuals contain the condensed results of many tests and checks made to assist the electrician in obtaining maximum performance from the equipment. The manuals are authorized for publication by the Chief of BuWeps and are printed in accordance with prescribed format.

As mentioned previously all BuWeps publications are assigned code numbers. The first two numbers indicate the general subject classification. Examples with which the AE will be concerned are 05 (instruments) and 03 (accessories, such as actuators, motors, and generators). These are typical, but are not to be construed as the only classifications of interest to the AE.

When provided, Operation Manuals contain information pertaining to the operation of the specific equipment and also the necessary checks and adjustments required for obtaining good operating conditions. These manuals are divided into the following sections—a general description of the equipment, the operating procedures, the operating checks and adjustments, and provisions for emergency operation of the system.

Service Instruction Manuals provide information concerning the preparation for use and the maintenance of the specific equipment by

operational activities. Such manuals are usually divided into seven sections as follows:

Section I, Description and Leading Particulars, gives a description of the equipment and the general principles of its operation. Included in the section is information on the interchangeability of components and any special electrical or mechanical characteristics of the system or components.

Section II, Special Test Equipment and Special Tools, lists all necessary special test equipment and tools (including test racks) which are used for making complete bench test of the system or the components. Any instructions necessary for modifying the test equipment for some special use or for the fabrication of special testing harness are also found in this section.

Section III, Preparation for Use and Reshipment, is divided systematically, showing the method by which the particular equipment should be handled from the time it is received until it is ready for use by the operator. The section contains general information on uncrating and assembling the equipment on the test bench or in the aircraft, removing it from the aircraft, and recrating it for shipment. Detailed descriptions of cable fabrication and the connections of cables to the components are also included. Applicable data on any checks and adjustments required during installation of the equipment are found in this section.

Section IV, Theory of Operation, presents a general description of the particular system first, and this is followed by the detailed explanations of the individual circuits. The general description is usually given from the viewpoint of circuit developments, and block diagrams are used to trace the development path.

Section V, Organizational and Operational Maintenance, provides the instructions essential for the maintenance of the equipment and indicates the maintenance activities which perform it. Included are the preflight and daily inspections and tests, the bench test procedures, and the troubleshooting methods to be used by these activities.

Section VI, Field Maintenance, includes the instructions required for the servicing of the equipment at the field maintenance levels. In addition to alinement and parts removal procedures, information is given for checking component functions by means of performance checks. Also contained in this section are systematic trouble isolation procedures which assist in localizing a defective part or component to a circuit or group of circuits, depending upon the nature of the equipment.

Section VII, Diagrams, contains all the necessary diagrams for the maintenance and interconnection of the system. These include complete schematic and wiring diagrams of the system or its components for use in trouble analysis. Also included are voltage, resistance, and cabling charts of the equipment.

The Overhaul Instruction Manual provides detailed information for overhauling the electrical equipment and/or component. This includes such procedures as disassembly, cleaning, repair, recalibration, testing, and any other steps necessary for complete overhaul. The manual is issued primarily to overhaul activities because the nature of the work described is beyond the capacities and facilities of field maintenance activities.

The Illustrated Parts Breakdown (IPB) contains detailed illustrations and listings of the components and parts of the equipment for which it is issued. The main value of the IPB for the Aviation Electrician's Mate is its usefulness when ordering parts for replacement purposes. There is also an illustrated parts breakdown for an entire aircraft. This breakdown is useful for the same purpose.

Revisions are prepared and distributed when it becomes necessary to modify the manuals. When properly entered, the revisions serve to keep the manual an official source of the latest information applicable to the equipment. The available manuals and the revisions are listed in NavSandA 2002, Section VIII and its supplements. By making periodic checks of these, it is possible to determine which revisions are current and should be included in the manual.

INSTRUCTIONS AND NOTICES

The Navy Directives System is used throughout the Navy for the issuance of nontechnical directive type releases. Some of these prescribe policy, organization and methods, or procedures, and others contain general information. This directives system provides a uniform plan for issuing and maintaining directives. Conformance to the system is required of all bureaus, offices, activities, and commands of the Navy. Two types of releases are authorized under the plan—Instructions and Notices.

Information pertaining to action of a continuing nature is contained in Instructions. An Instruction has permanent reference value and is

ve until the originator supersedes or s it. Notices contain information pertain- action of a one-time nature. A Notice does ve permanent reference value and contains ions for its own cancellation.

r reasons of identification and accurate all directives can be recognized by the tor's authorized abbreviation, the type of e (whether an Instruction or Notice), a t classification number; and in the case of tions only, a consecutive number. Be- of their temporary nature, the consecutive r is not assigned to Notices. This informa- assigned by the originator and is placed h page of the release.

e manner of numbering and identifying ves can be better understood by con- ng a typical identifier:

SECNAV	INST.	5215.	1A
(a)	(b)	(c)	(d)

Here the authorized abbreviation of the tor of the directive is placed.

This part refers to the type of release, case an Instruction.

This is the subject number which is ined by the subject matter of the direc- nd is obtained from the Table of Subject fication Numbers.

Following the period is the consecutive r which is found only on Instructions. An tor would assign consecutive numbers to consecutive instructions with the same t Classification Number. In the example the Subject Classification Number 5215 ns "Issuance Systems." If the originator, , issued additional Instructions dealing ssuance systems they would be assigned r 5215.2, 5215.3, 5215.4 and so forth. t classification numbers are listed in the of Subject Classification Numbers found Nav Instruction 5215.1A. This table con- a numerical and alphabetical listing of rs with their related subjects, and is of erable value for reference use when in- ion or instructions of a particular nature sired. This Instruction contains all nec- information concerning the use and pro- s of the Navy Directives System.

ARY SPECIFICATIONS

hough military specifications are gen- considered to be in a different category the other publications discussed in this chapter, some mention of them should be made here.

A military specification is a written document containing the details of construction and minimum standards for an item of equipment or material which has been ordered by a using activity. In the case of the Armed Forces, specifications are necessary to insure that the item ordered meets all the requirements for which the government is paying, and that the item will perform all the necessary functions.

The Armed Forces now procure most of their material and equipment under a coordinated program. Items procured under this program are assigned a military (MIL) specification number. Specification numbers are not always necessary in identifying items, since many are normally identified by federal stock number, manufacturer's part number, trade names, etc. However, when in doubt as to the identity of an item, the specification number is another means.

Specifications are revised from time to time, and specification numbers are often changed, canceled, or superseded. An index titled List of Specifications and Standards, NW 00-25-544, reissued periodically under the supervision of BuWeps, lists all specifications in effect and those recently canceled. This publication is available in the technical library.

AVIONICS CHANGES

Avionics Changes (formerly called Electronic Material Changes) are issued by BuWeps to promulgate technical instructions necessary for the addition, removal, or replacement of a part, modification to circuitry, and other necessary changes. Modification of electronic material is normally limited to modification of parts, subassemblies, assemblies, components or complete equipments, and interconnecting wiring. Instructions for the substitution of components of an ASW electrical system may be issued by an Avionics Change, provided that the following requirements are met:

1. The change must have negligible effect on weight and balance of the aircraft.
2. The aircraft structure and/or nonrelated equipment(s) must not be affected.

NOTE: Substitution is defined as removal of the equipment or component and its replacement with a similar equipment or component to perform the same or additional functions.

Modifications which fail to satisfy the above requirements are handled in accordance with Airframe Change (formerly Aircraft Service Change) procedures.

Avionics Change should be performed in accordance with the instructions contained in the directive authorizing the change.

Performing these changes promptly and with the utmost of care is very important. They keep your equipment up to date and interchangeable with replacement units, and they help to prevent possible failures. After the change has been completed, check it over for good connections and security of components, and give it a complete functional test.

Refer to the Avionics Changes at various times. For example, some of the changes are not to be accomplished until the part or parts have failed. In this situation when a part fails it is advisable to check for any changes that may apply to the failure. There may be times when you will find that a circuit differs from the schematic diagram, and by checking the files it may be found that this difference is due to an Avionics Change. In this example the Service Instruction Manual, which contains the schematic, has not been corrected to comply with the change; this accounts for the difference between actual circuit and schematic.

Avionics Changes are mandatory and must be complied with as directed in the change. All activities operating aircraft must maintain a complete file of effective Avionics Changes.

AVIONICS BULLETINS

Avionics Bulletins (formerly called Electronic Material Bulletins) are issued by BuWeps to promulgate technical instructions on operation, inspection, alinement, maintenance procedures, and so forth.

AIRFRAME CHANGES

Airframe Changes contain instructions for making modifications to a given model of aircraft. They may cover addition's, omissions, or replacements of parts. They also cover any changes in the material of which the parts are made. Airframe Changes are issued after delivery and acceptance of the aircraft by the Navy and are usually for the purpose of improving flight or safety characteristics of the aircraft. They are originated by technical personnel of BuWeps.

Airframe Changes are classified as IMMEDIATE ACTION, URGENT ACTION, or ROUTINE ACTION.

Immediate action changes are incorporated prior to removal of the restrictions imposed (prior to further flight of the aircraft) and immediately upon receipt of approved engineering data and material required.

Urgent action changes are incorporated not later than the next occurring perodic aircraft maintenance inspection, or comparable maintenance cycle, after receipt of approved engineering data and material required.

Routine action changes are incorporated only if prescribed by the cognizant controlling custodian.

Related to the Airframe Change are the Single Action Maintenance Instruction (SAMI) and the Continuing Action Maintenance Instruction (CAMI). These are discussed later in this chapter.

NAESU DIGEST

The Naval Aviation Engineering Service Unit (NAESU) each month prepares and publishes the magazine Digest of U. S. Naval Aviation Electronics. The digest contains information on electrical and electronic equipment relative to operation, maintenance, installation, and supply. This is an excellent source of information dealing with new equipment and new ideas on older equipment. It gives the latest procedures for speeding test, calibration, and alinement of equipment now in use as these methods are developed by NAESU and other activities. In general, it is, as the name suggests, a digest of all the latest information pertaining to work in electronics. It should be on the "must" read list for all hands and always available for ready reference.

INSTALLATION MANUAL

Installation Practices for Aircraft Electric and Electronic Wiring, NW 01-1A-505, is the basic source for most of the recommended practices and techniques to be used for installing, repairing, and maintaining aircraft electric wiring. The information contained in this manual was obtained from the country's leading airframe manufacturers, airline operators, and overhaul activities. Long experience has shown that certain jobs or operations are best accomplished by using certain materials and

techniques. The AE should be thoroughly familiar with these, because they are the means by which he actually applies his theoretical training.

There is usually a considerable gap between learning electrical theory and then actually working as an AE. The installation manual goes a long way toward bridging this gap. It gives specific details of exactly how to do a great number of small operations. A few of these are soldering, splicing, lacing and tying, safety wiring, and working with conduit. Clear illustrations help make this manual easily understandable. Verbal instructions are kept to a minimum. The AE should find this manual a valuable aid in helping him form his work. If this publication is not in the shop, ask the leading petty officer to obtain it.

AIRCRAFT STRUCTURAL
HARDWARE (NW 01-1A-8)

This is an engineering technical manual for aircraft repair and is designed to assist personnel engaged in the maintenance and repair of aircraft. The section of the manual that can be most helpful to the AE presents information dealing with electrical wiring, tubing systems, and flexible hose and fittings.

HANDBOOK OF OPERATION AND
SERVICE INSTRUCTION ON AN
ELECTRICAL CONNECTORS,
AN 03-5-90

This handbook covers the description, selection, preparation, installation, and maintenance instructions for the commonly used AN connectors. It may serve as a source of general information for the technician and also as a training guide for those inexperienced in the construction of cables using AN connectors.

ELECTRONICS INSTALLATION
AND MAINTENANCE BOOK;
TEST METHODS AND PRACTICES;
NAVSHIPS 900,000.103

This manual is written to meet the technician's need for a complete and convenient source of information and reference data relating to the testing and maintenance of electronic equipment. The wide scope of information contained in this manual makes it equally valuable for the beginning technician and the technician who has much experience. The contents of the manual's seven sections are as follows:

1. General Testing Information. This section discusses the importance of and functional divisions of testing with an explanation of the basic measurements. In addition, it outlines the hazards encountered in testing and discusses safety precautions relative to testing electronic equipment.
2. Test Equipment. This section describes the function of basic test circuits and the combination of these basic circuits into complete test equipments. Circuit diagrams and functional descriptions of typical test equipments are presented. General testing techniques are explained and safety precautions applicable when using specific types of test equipment are emphasized.
3. Basic Measurements. This section contains information on the many measurements utilized in testing electronic equipment, including the common and widely used parametric measurements as well as more complex and specialized measurements.
4. Test Techniques and Practices. This section explains the testing techniques and practices used to operate, maintain, and repair electronic equipment. These techniques and practices utilize the types of test equipment described in section 2 and the fundamentals of basic measurements discussed in section 3.
5. Care, Repair, and Calibration of Test Equipment. This chapter prescribes practices, procedures, and techniques to be followed in the mechanical and electrical repair of test equipment.
6. Merit Measurements. This section explains and discusses the factors contributing to the quality of electronic equipment operation.
7. Special Circuit Components. This section is devoted to the theory of electronic circuit components and electronic circuits.

The appendix to this manual contains electronics reference data of use to the technician.

SEMICONDUCTOR DEVICE
REPLACEMENT GUIDE
NW 16-1-530

This publication contains replacement, technical, and mechanical information on all semiconductor devices listed in the Navy Supply System.

RECORDS AND REPORTS

STANDARD AIRCRAFT INVENTORY LOG

In the past, there has always been a problem in maintaining custodial control and location information on bureau-controlled aeronautical components and aircraft related equipment. In order to maintain an unbroken chain of custodial responsibility incident to the transfer and acceptance of naval aircraft, the Standard Inventory Log was developed by the Navy to be used as an instrument of transfer. In the interest of standardization among the armed services, the Aircraft Inventory Record has been designed by the Department of Defense for this purpose. Records (instead of Logs) are now being prepared by the Navy for new production aircraft when the old Logs are revised.

With remote exceptions, no aircraft may now be transferred or accepted without an Inventory Log or Record. On these occasions, an inventory of the aircraft and its equipment must be accomplished, based on the items of equipment and material contained in the applicable Log or Record.

Although the Log and Record serve the same purpose, there are some minor differences in their format and categorical listings. In general, the determination as to whether items are, or are not, subject to listing in these publications without regard as to whether they are contractor or government furnished and contractor or service installed is governed by the following:

1. Items essential to the execution of the designated missions of the aircraft, such as armament, electronics, photographic equipment (excluding cameras other than for primary missions) and special instruments, are included.
2. Items of equipment which are rigidly fixed and considered to be a basic or integral part of the airframe, such as engines, propellers, wheels, tires, and brakes, are excluded. In the case of the Aircraft Inventory Record, standard instruments are also excluded.
3. Special equipment items essential to the safety or comfort of the crew such as bedding, liferafts, Thermos bottles, crash axes, and portable fire extinguishers are included. Comparable items which are personal issue or furnished on squadron allowances are excluded.
4. Loose equipment delivered with the aircraft, such as covers, mooring kits, and jack pads, for which stowage provisions have been incorporated in the aircraft, are included.
5. Items subject to pilferage or readily convertible to personal use, such as clocks, Thermos jugs or bottles, bedding, and first aid kits, are included. Comparable items which are personal issue or furnished on squadron allowances are excluded.

The Standard Inventory Log is subdivided into groups of equipment (e.g., instrument and navigation equipment, armament equipment, and electronic equipment). The components are listed in alphabetical sequence and according to their location in the aircraft, with the exception of the electronics equipment, in which case all components of an equipment are listed in one place regardless of their location in the aircraft. Stock numbers are also supplied for individual items, and are used for ready reference when replacements are required.

The Aircraft Inventory Record includes a sectional breakdown diagram of the applicable aircraft. This diagram consists of a side elevation and/or the plan view of a wing, or in the case of twinboomed or flying wing aircraft, the perspective view.

To facilitate inventorying, the sections of the diagram are identified by letters, the letter "A" being assigned to the foremost section, "B" to the next, and so on, generally to the rear of the aircraft. The letter "R" as part of the item number, denotes items mounted on the exterior of the fuselage, and the letter "F" denotes items to which access is gained from the fuselage. Subdivisions of sections may be identified by a lower case letter such as "Aa", "Ac", etc.

The equipment list portion of the Record is divided into sections, each of which lists the items pertaining to a particular section of the aircraft, as indicated on the sectional breakdown diagram. Within each section, individual items are numbered as nearly as possible in the sequence of their physical location in the aircraft without regard to their relation to specific equipment. Stock numbers are not supplied as part of the equipment listing in Inventory Records.

One Standard Inventory Log in general is issued as applicable to one aircraft model and designates material and equipment peculiar among the various applicable versions and bureau numbers. The Aircraft Inventory Record is issued as applicable to one aircraft for a specific bureau number.

Blank columns are provided on the inventory pages of the Log and Record, in order that

transferring and receiving activities may jointly inventory and indicate the quantity of each item ascertained to be on board the aircraft at the time of transfer. A RECEIPT ENDORSEMENT LOG in the Standard Inventory Log, and a CERTIFICATE AND RECORD OF TRANSFER in the Aircraft Inventory Record are provided so that transferring and receiving activities may sign, indicating by column applicability, the items on board the aircraft.

Upon transfer of an aircraft, representatives from the transferring and receiving activities jointly inventory and record, in the appropriate column, the quantity of each item which is ascertained to be on board the aircraft at the time of transfer. When a ferry pilot, or a naval vessel is involved in the transfer, two inventories are made, one prior to the ferry flight or embarkation, and one upon completion. In the former instance the ferry pilot or vessels is considered to be the receiving activity, and in the latter instance the transferring activity.

MAINTENANCE RECORDS

Certain basic forms and procedures are set forth as guideposts to standardize maintenance practices. The AE will find it necessary to become familiar with the purpose and the actual filling out of these forms. He will also find that the extra time needed to make the proper entries will be repaid many times when the information is eventually needed.

NavWeps Form 4710/8 is available for the use of maintenance administrators as the standard form for the interpretation and/or amplification of technical directives and maintenance requirements received from higher authority or to implement local instructions. It is usually prepared by the cognizant division; however, it may be drafted by any division designated by the aircraft maintenance officer. A review of the draft should be conducted by the quality control officer prior to approval of the aircraft maintenance officer.

The Maintenance Instruction must be prepared carefully, with attention to the precept that it is the instrument by which the division officer directs his men. Command directives in the form of messages are often so brief that they need considerable amplification and background information to be understandable at the working level. Directives in either form may be received that have been prepared for all aviation activities and are lengthy and detailed. Only parts of these directives may be applicable locally and they need condensation and selection to adapt them to local conditions. There are three purposes for which the Maintenance Instruction may be used: work of a one-time nature (SAMI); work that may recur at intervals (CAMI); and dissemination of technical information within the activity (TIMI).

Single Action Maintenance Instruction (SAMI)

A SAMI is issued for the performance of work of a one-time nature. The work so ordered is such that it will be completed on one aircraft model or piece of equipment by carrying out the instructions set forth, and will not require further action at any time or in any situation on that aircraft model or piece of equipment. An example of a SAMI is an Airframe Change on all bureau numbers of a certain model of aircraft. When preparing this Maintenance Instruction, the box labeled "Single Action" at the top of the sheet must be checked.

When NavWeps Form 4710/8 is used as a SAMI, the checkoff list furnished on the reverse side of the sheet may be used by the cognizant shop to enter all the bureau numbers of affected aircraft or serial numbers of equipment, and each may be checked off by date completed. (NOTE: A Work Order and Work Accomplishment Record, Form 4710/5, will be issued by maintenance control for each aircraft or piece of equipment involved.)

Continuing Action Maintenance Instruction (CAMI)

A CAMI is prepared and issued when a directive or situation dictates that specific work must be accomplished at recurring intervals based on elapsed time or the occurrence of a particular incident or condition. It is important that each CAMI clearly state when the prescribed work is to be performed.

Supporting work orders are issued at the time of occurrence of the incident or the expiration of the time interval, as appropriate, to insure that the work is actually accomplished. A CAMI is identified by a check in the "Continuing Action" box (fig. 24-1 illustrates a CAMI) at the top of the NavWeps Form 4710/8.

MAINTENANCE INSTRUCTION
NAVWEPS FORM 4710/8 (5-62)

☐ TECHNICAL INFORMATION ☐ SINGLE ACTION ☒ CONTINUING ACTION

ORIGINATING ACTIVITY	DATE	MAINTENANCE INSTRUCTION NO.
VF-124	22 Jun 62	C-189

SUBJECT

Non-Trip-Free circuit breakers; replacement of

REFERENCE

EMB 13-54

APPLICATION

All aircraft

ACTION

1. Discussion: The purpose of this instruction is to provide for the replacement of any non-trip-free circuit breakers (type AN-3160, AN-3161, and AN-3161P) which have been closed on, or which have been held closed against any uncontrolled overload current which would otherwise have caused normal tripping of the circuit breaker.

Non-trip-free circuit breakers covered by Specification MIL-C-7079 are required to automatically recalibrate within their original specification limits after having been held closed against overloads of 400% rated current for ten (10) seconds at 25° C ± 1° and 25% rated current for ninety (90) seconds at 25° C ± 1°.

1. ACTION:

a. Any pilot or mechanic who has had occasion to hold in a non-trip-free circuit breaker against an overload fault shall report such action to maintenance control.

b. Remove and replace non-trip-free circuit breakers which have been closed or have been held closed against any uncontrolled overload current with one of the same type and rating.

WHEN TO BE DONE

AS REQUIRED

MATERIAL REQUIRED	MATERIAL ORDERED ON REQUISITION NO.
Circuit breaker of same type and rating as that being replaced.	

WORK RESPONSIBILITY	LOG BOOK ENTRY (ENTRIES) REQUIRED
Avionics/Weapons Division	☐ YES *(State entry required)* ☒ NO

SUBMITTED BY *(Signature of Division Officer)*	APPROVED BY *(Signature of Maintenance Officer)*
P. W. CROTWELL, LT. USN. QUALITY	CONTROL L. E. JOHNSON, CDR. USN

(See instructions on reverse)

Figure 24-1.—Continuing Action Maintenance Instruction.

Technical Information Maintenance Instruction (TIMI)

A TIMI is prepared and issued when a directive or situation requires that technical information be promulgated within an activity. When it is necessary to disseminate information, such as techniques and local policy, which does not direct the accomplishment of specific work at definite intervals, but which is sustaining in nature, a TIMI may properly be issued; for example, procedures and techniques for aircraft fueling. The NavWeps Form 4710/8 is identified as being a TIMI when the "Technical Information" box at the top of the form is checked.

WORK ORDER AND WORK ACCOMPLISHMENT RECORD (WOWAR)

A Work Order and Work Accomplishment Record, NavWeps Form 4710/5 (supersedes NavAer 5230B), is prescribed and provided for use of aircraft maintenance activities to facilitate the direction and control of the maintenance operation as well as to record the accomplishment of completed work. The form further provides information which may be used for developing accurate job time estimates for scheduling purposes. These forms are provided in unit sets comprised of an original and three copies, each having a different color. The original is white. The copies are pink, yellow, and green.

This form and procedures related to its use represent an improvement in the line of communication between the staff and production divisions of the aircraft maintenance department. The preparation and completion of the form together with routing and final disposition are described in the following paragraphs. Figure 24-2 illustrates the front of the WOWAR form, and figure 24-3 illustrates the back.

Work Order Preparation

Although the WOWAR may be originated from several locations within an activity, it has been found that workload control is most efficiently and effectively accomplished by originating work orders only from the workload scheduling element of the maintenance control office. Information in this and the two following sections is predicated upon the assumption that this is the case. The front portion of the WOWAR form is completed by the originator as follows:

1. Activity. Enter the designation of the maintenance activity (e.g., VA-44, VP-5, NAS, etc.).
2. Work Order No. The originator assigns a work order control number before routing the copies. These numbers may be sequential or may be any identifying number such as the "date/time" number the order is issued.
3. Route To. Specify, if necessary, the division, branch, etc., for which the copy is intended.
4. Assignment and Authorization. Identify the aircraft by type, side number, and/or bureau number, and note the date and time the work order is issued. Identify the division/shop to which the work order applies and enter an authorizing signature. The "action" assignment carries with it the responsibility and necessary authority for initiating the action to assure the work is accomplished, for seeing that it progresses smoothly and is completed satisfactorily, and for returning the original (white copy) of the work order to the maintenance control office.
5. Work Order Data. By checking the appropriate boxes, indicate the status of the aircraft, the work priority, whether a flight test is required, and whether the "yellow sheet" requires a signature. As completely as possible, describe the reported discrepancy of work required and, if applicable, cite the special instructions, references, or directives to be used in completing the job. Space is also provided in this section of the work order to identify the divisions or shops from which assistance may be required to complete the repairs ordered. Assistance, in this sense, would not necessarily mean repair since a separate work order would be required if repairs were involved. Upon completion of repairs and inspection, the assist shops would replace removed items and inspect the affected area.

Routing

1. The original (white copy) is forwarded to the "action" division or shop designated to perform the work. When the work order is issued to comply with a Change or other type directive, a copy of the directive may be attached to the white copy. Upon completion of the job, the work order should be filled in completely and returned to the maintenance control office (via the quality control division if required). The white copy is

WORK ORDER & WORK ACCOMPLISHMENT RECORD
NAVWEPS FORM 4710/5 (5-62)

VF-174
(Activity)

WORK ORDER NO. 236

ROUTE TO: Avionics Division

ASSIGNMENT AND AUTHORIZATION

TYPE A/C	SIDE NO.	BUNO	DATE/TIME	ACTION DIVISION/SHOP	WORK AUTHORIZED *(Signature)*
F-8E	110	150145	27 May 65 1315	Electric/Instr	N. E. Roberts AECS

WORK ORDER DATA

A/C STATUS	PRIORITY	FLIGHT TEST	YELLOW SHEET—SIGNATURE REQUIRED
[X] DOWN [ ] UP	[X] ROUTINE [ ] URGENT [ ] DEFERRED	[ ] YES [X] NO	[X] YES [ ] NO

DISCREPANCY AND/OR WORK DESCRIPTION

Pilot reports fuel quantity gage inoperative.

SPECIAL INSTRUCTIONS, REFERENCES OR DIRECTIVES

ASSIST DIVISION/SHOP	DATE/TIME	MAN-HOURS	SIGNATURE

Figure 24-2.—Work Order and Work Accomplishment Record, front page.

TECHNICAL DATA				
PARTS REPLACED *(Nomenclature)*	SERIAL NUMBERS		REASON FOR REPLACEMENT	FUR *(No.)*
	OLD PART	NEW PART		
Simulator	A342	A563	Broken connector	0458

WORK ACCOMPLISHMENT RECORD

WORK ACCOMPLISHED *(In detail)*

1. Replaced simulator.

2. Calibrated fuel quantity gage.

ACTION DIVISION/SHOP	WORK ACCOMPLISHED BY *(Signature)*	DATE/TIME	MAN-HOURS	SUPERVISOR'S SIGNATURE
	N.A. Mitchell, AE2	5/27/65 1535	2.0	C.M. Temple, AEC

INSPECTOR W.D. Dunn, AE1 *(Signature)* 5/27/65 1545 *(Date/Time)*

YELLOW SHEET ☐ SIGNED OFF ☐ NOT REQUIRED

AIRCRAFT NOT READY DATA *(Notify Maintenance Control)*

DATE/TIME	SUPPORT EQUIP.	ADMP	ANFE
START			
END			

ADMINISTRATIVE ACTION
(Circle "action" item in each block and initial when complete)

STATUS BOARD	FLIGHT TEST	WEIGHT & BALANCE	FUR INITIATED	LOG BOOK ENTRY
N.E.R.	N.E.R.	N.E.R.	N.E.R.	N.E.R.
POST / NOT REQ'D	COMPLETE / NOT REQ'D	COMPLETE / NOT REQ'D	COMPLETE / NOT REQ'D	NOT REQ'D / AIRCRAFT / ENGINE / ACCESSORY & COMPONENT

OTHER ACTION *(Specify)*

NO FURTHER ACTION REQUIRED N.E. Roberts, AECS *(Signature)*

NAVWEPS FORM 4710/5 (5-62) (BACK)

Figure 24-3.—Work Order and Work Accomplishment Record, back page.

filed upon certification that no further action is required and is retained for 6 months.

2. The pink copy is an extra copy that is forwarded with the original to the "action" division or shop. This copy may be used there for controlling the work. The pink copy is retained and may be filed by the "action" division or shop upon completion of the specified work.

3. The yellow copy is retained in the workload scheduling office and may be used to control outstanding work orders. The yellow copy may be destroyed after the white copy is returned and certification is made that no further action is required.

4. The green copy is routed directly to the quality control division for information and appropriate action as required.

Completion of WOWAR

The reverse side of the work order form provides space on the original and pink copy only to be completed by the affected division or shop. Spaces are completed as indicated in the following paragraphs:

1. Technical Data. The nomenclature of the parts replaced as well as serial numbers of all removed and replacement parts are entered in the Technical Data Section. Also provided is space for entering the FUR number on which the failure of the item was reported. A concise "Reason for Replacement" should be entered in the appropriate space.

2. Work Accomplishment Record. Enter all corrective action taken. A space is provided for the AE responsible for the accomplishment of the work to enter his signature, together with the date and time the job was completed and the manhours expended. Space is also provided for the "action" division supervisor's signature as well as the signature of a designated inspector. The inspector should either be a quality control inspector or a collateral duty inspector who, by signing in the space provided, verifies that the work is satisfactory (or does not require inspection). Information on aircraft not-ready due to lack of serviceable ground support equipment, aircraft maintenance delays for parts, and aircraft not fully equipped (ANFE) delays should be entered in the space provided. The maintenance control office must be notified whenever these delays are experienced in the execution of a work order. Depending upon local procedures, an indication of whether the "yellow sheet" has been "signed off" or "not required," together with the initials of the person making this notation, is entered either by the "action" division or shop or by the maintenance control office.

3. Administrative Action. This portion is completed by the maintenance control office and is self-explanatory. The purpose of this section is to insure that all administrative action is completed on the work order prior to certification that no further action is required.

A flow chart which visually depicts the use of the Work Order and Work Accomplishment Record discussed in the foregoing is provided in figure 24-4.

AERONAUTICAL MATERIAL WORK ORDER

An Aeronautical Material Work Order, NavWeps Form 4710/6, is provided for the use of aircraft maintenance activities to facilitate the direction and control of component and equipment repair as well as to record the accomplishment of completed work. The form further provides information which may be used for developing accurate job time estimates for scheduling purposes. This form is not used to direct the removal of an item from or replacement of an item on an aircraft. A Work Order and Work Accomplishment Record form is properly used for this purpose. The Aeronautical Material Work Order has been specifically devised so that it may be originated from any one of three organizational elements within a maintenance activity. These are workload scheduling in the maintenance control office, from any division or shop to direct and control work within that division or shop, and from the material control division when directing component repair maintenance.

Detailed instructions for preparing the Aeronautical Material Work Order are contained on the back of each form. The form is prepared in duplicate so that the originator may retain a copy for control purposes.

ACCESSORY AND COMPONENT SERVICE RECORD

Form 13090/29 is an accessory service record maintained for an aeronautical accessory when required by BuWeps. Accessories requiring service records are listed in the following publications and their revisions:

1. Periodic Maintenance Requirements Manuals.

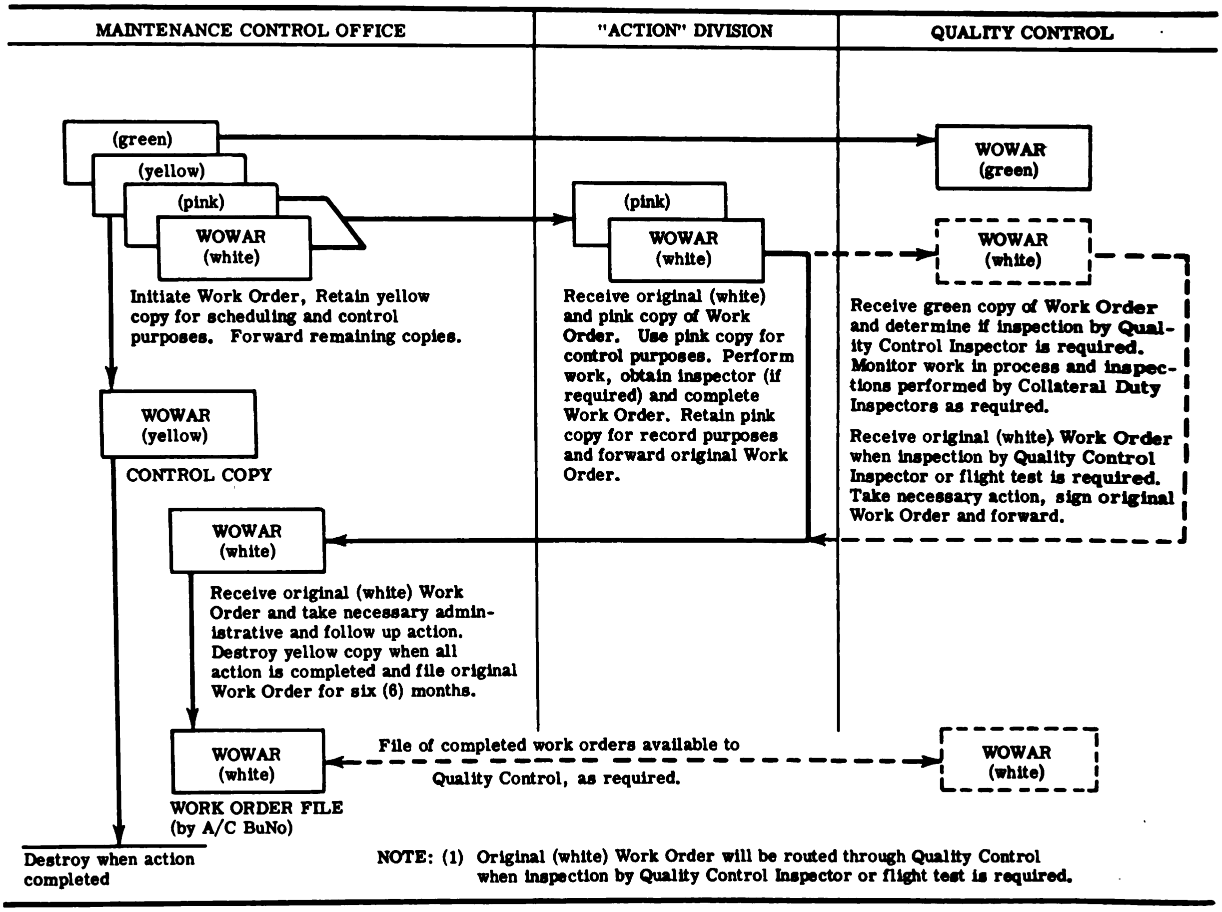


Figure 24-4.—Flow chart for Work Order and Work Accomplishment Record.

2. General Reciprocating Engine Bulletin No. 186.

3. Various specific Engine and Accessory Bulletins.

Original accessory service records are initiated in accordance with the following:

Service records for accessories installed on or shipped with major aeronautical equipment (equipment requiring an Aeronautical Equipment Service Record) are initiated by the activity which originally accepts such major equipment for the Navy. Service records for accessories installed on or shipped with new aircraft are initiated by the activity originally accepting the aircraft for the Navy. Service records for new accessories received through the Navy supply system are initiated by the activity requisitioning the item for service. Overhaul and Repair activities insure that service records accompany overhauled accessories either as part of the logbook or securely attached to the item if it is returned to the supply system. These last records are not normally originals but may, in some instances, be new transcriptions or consolidations of old service records.

If records are lost, it is the responsibility of the activity having custody of the accessory at the time of loss to initiate a new record containing all available information. Activities receiving accessories (other than new) without records request corrective action from the previous custodian. In certain instances where corrective action cannot be obtained, the activity having custody of the item initiates a new accessory record.

When record cards become damaged or mutilated, the activity having current custody intiates a new record. All information is to be transcribed to the new record.

Since this record contains information of importance in compiling usage data, it is imperative that all available required information be entered on it. When a record contains no space for additional entries, a new card is prepared and both must accompany the accessory until such time as the record is consolidated at rework.

Technical directives are accounted for by all activities by number for each applicable directive that has been incorporated. In order to conserve space, more than one directive number may be entered on one line, provided that the date incorporated is the same. Original accepting activities and Overhaul and Repair activities, when initiating new records or transcribing information from old records, may list on one line (space permitting) all incorporated technical directives regardless of the compliance date or activity. A general discussion of technical directives to be recorded on this form is contained earlier in this chapter.

The Replacement Due At time (or date) is calculated when the item is originally installed and reflects the total numbers of hours on the aircraft or equipment or the date when the item is to be replaced. For example, a "500-hour" component installed on an aircraft with 795 hours will have the figure 1,295 placed in the REPLACEMENT DUE AT space. This figure may be indicated either on the card (in pencil) or on a suitable insert placed over the card in the holder.

Accessory records may be destroyed when the item is no longer serviceable and the record is no longer required. Figure 24-5 illustrates a Service Record Card for an a-c generator.

SHOP LOGBOOKS

Each shop maintains its own logbook as a record of the work performed by that shop. When an aircraft comes in for a check, the type of check to be performed and any discrepancies that are listed on the inspection sheets are entered in the shop logbook. Upon completion of the check, the shop log is "signed off" at the same time the inspection sheets are completed and turned in to the maintenance office. All discrepancies that occur on the aircraft between checks are also logged in the shop log and signed off when completed.

The format for these logs will usually vary between activities but they normally include the following: Date, aircraft number, discrepancy, corrective action, date completed, and signature of the crew leader or the man performing the work.

In some cases shops will have, in addition to the daily or master logbook, a logbook for each aircraft. The information from the daily or master logbook is transferred each day to the logbook for the aircraft concerned. This enables the shop personnel to obtain information on previously performed maintenance on a particular aircraft without looking back through the daily or master logbook.

These logbooks are very important to the particular shop concerned and should be kept neat and up to date. All entries should be correct and clearly stated. These logbooks are of no value to the shop unless they are properly maintained.

MALFUNCTION REPORTING PROGRAM

This section describes the Bureau of Naval Weapons Malfunction Reporting Program in effect at the writing of this manual. The program described in this chapter is an interim program. A new system for collecting and reporting malfunction data has been introduced. The new system has been designed to facilitate a more complete and efficient analysis of such information through the use of electronic data processing procedures. It is expected that about 2 years will be required to phase in the new program. In-production aircraft weapons systems, such as described later in this chapter, will receive first attention during the phasing in period, with other weapons systems to follow in due time.

The interim Malfunction Reporting Program described in this chapter is based on BuWeps Instruction 4700.2A.

A Failure, Unsatisfactory or Removal Report (FUR), designated NavWeps Form 13070/3, has been established as the sole reporting document for the interim Malfunction Reporting Program. This form expands data collection over that of certain older forms and combines the functions of those reports into a single form.

Activities concerned with the operation, maintenance, inspection, or repair of the in-production type aircraft listed below submit Failure, Unsatisfactory or Removal Reports for each unscheduled maintenance action, failure, malfunction, removal, and replacement or rejection of materials, parts or assemblies installed in or received for installation in in-production aircraft, associated material, and

INSTALLATION DATA							REMOVAL DATA				
DATE	INSTALLED ON	SERIAL NO.	BY (ACTIVITY)	TOTAL A/C HOURS	ACC./COMP. HRS. SINCE NEW	ACC./COMP. HRS. SINCE O/M	DATE	TOTAL A/C HOURS	ACC./COMP. HRS. SINCE NEW	ACC./COMP. HRS. SINCE O/H	REASON FOR REMOVAL ACTIVITY & FUR NO.
1-13-61	TF-1	136776	VR-21	1726	0.0	NA	1-17-63	2764	1057.2	NA	High Time VR-21 Det. Japan FUR#058
-20-64	TC-45J	51077	NAS Mfs	Unk.	1057.2	0.0	7-15-64	Unk	1231.3	174-1	Voltage Unstable NAS Mfs FUR#0608
9-1-64	T-28B	138310	NAS Mfs	3846	1231.3	174.1					

TECHNICAL DIRECTIVES

TYPE DIRECTIVE AND NUMBER	STATUS	CAT.	DESCRIPTION	COMPLIANCE BY (ACTIVITY)	COMPLIANCE DATE	SIGNATURE
EMB 2-56	INC	R	CHECK BEARINGS	NAS Alameda	4-19-63	Paul J. Spera

OVERHAUL AND SIGNIFICANT REPAIR

DATE	OVERHAUL OR REPAIR(SPEC.)	AIM NO.	ACTIVITY	REMARKS AND MAJOR PARTS REPLACED	SIGNATURE
4-19-63	OVERHAUL	1	NAS Alameda	Brushes, Bearings	Paul J. Spera
8-24-64	REPAIR		NAS Mfs	Control	Herman E. Boccia

THIS RECORD MUST ACCOMPANY THE ITEM AT ALL TIMES WHEN THE ITEM IS INSTALLED. THIS RECORD THEN BECOMES PART OF THE AIRCRAFT OR EQUIPMENT LOG BOOK.

ACCESSORY AND COMPONENT SERVICE RECORD NAVWEPS FORM 13090/29(1-63) **PERMANENT RECORD**

STOCK NUMBER	MANUFACTURER	RETIREMENT TIME (If Applicable)	REPLACEMENT INTERVAL	REPLACEMENT DUE AT
RP6125-607-1686-D334	Leland	NA	1000 Hrs	4672

NOMENCLATURE	SERIAL NUMBER	PART NUMBER
INVERTER	MX 1699	MGE-57-1

Figure 24-5.—An accessory and component service record card.

support equipment. Reports are submitted on all removed parts whether accountable or not and on all unsatisfactory conditions where part replacement is not made. Reports are submitted on Air Force/Navy (AN), Military Standards (MS), National Aeronautical Standards (NAS), and bulk materials as appropriate, and on defects or deficiencies of change kits. In-production aircraft, for purposes of the Malfunction Reporting Program, are as follows:

A-4E Model
A-5 Series
A-6 Series
CH-46 Series
E-2 Series
F-4 Series
F-8E Model
H-2 Series
H-3 Series
P-3 Series
QH-50 Series
S-2D Model
S-2E Model
T-39 Series

Activities having cognizance over out-of-production aircraft, (which excludes those listed in the foregoing) submit FUR's on these aircraft on the following conditions only:

1. Safety of Flight AMPFUR's.
2. Urgent AMPFUR's.
3. AMPFUR's on material released for investigation.
4. AMPFUR's on discrepant new or overhauled material (deficient quality control).
5. Where material accountability is involved.

FUR forms are completed and submitted in accordance with instructions contained in BuWeps Instruction 4700.2A and instructions furnished with the forms.

Preparation of FUR Form

The FUR is provided in two types: one, a carbon-backed nine-page set and the other, a single-copy FUR. The FUR set is comprised of five separate sections, each of which is designed for a specific function. The reporting activity initiates the FUR report on the nine-page set whenever accountable material is removed and replaced, completing the necessary spaces as required by the preparation instructions furnished with each FUR set. (See fig. 24-6.)

In cases where repairs cannot be effected by the activity originating the report, the removed part or assembly and the complete FUR set, less the activity FILE copy, are delivered to the supporting Aircraft Maintenance Department (AMD) where the item is screened for repair and return to service. In such cases, the spaces on the FUR set pertaining to part condition and cause of trouble are left blank by the originating activity. The FUR is then completed, signed, and mailed by the AMD.

The single sheet FUR is prepared for all cases in which unsatisfactory conditions or materials are reported and part replacement is not required; repairs are effected and a part reused without requisitioning a new part, or the services of an AMD are not required; and where a Government Furnished Equipment (GFE) item is rejected by a government inspection activity. The single sheet FUR may also be used when a work copy is needed to record data for transcribing to the finished copy, and when additional copies are required.

The FUR form has provisions for the originator to submit a report in various categories and by certain priorities. Each report should be checked in the appropriate space to identify it as being a FUR, AMPFUR, Urgent AMPFUR, Flight Safety AMPFUR, or FOLLOWUP report.

A check in the FUR space indicates that the particular condition did not meet expected performance, life, or other expectation, but was not by itself critical in nature. A FUR is indicated when only the check-box area of the form is, or can be, completed. The FUR is a statistical data type report and is compiled for monthly review.

An AMPFUR (Amplified FUR) is similar to the FUR in nature, but provides amplifying remarks on the nature of damage, circumstances which revealed the damage, and photos or sketches of the damage. AMPFUR's are given more detailed review and analysis than that accorded FUR's.

URGENT AMPFUR's are used when the originator feels that the condition being reported seriously affects reliability or is of concern to local operations or maintenance. This category is also used when material is to be held for possible investigation. URGENT AMPFUR's are accorded priority processing and distribution and are individually reviewed for corrective action. In some situations, the originator may elect to make the initial URGENT AMPFUR by message. In such cases the Form 13070/3 is still required to be submitted and the date/time

Report Symbol BUWEPS 13070-3

1. Reporting Activity VF-191	2. Report Ser. No. 0989	3. Date Of Trouble 5-16-65	4. Installed In Aircraft/Arrest. Gear/Catapult/Support Equipment Model F-8E; Buno or Ser. No. 150326	5. Aircraft Logbook Time 1843.3

System, Set Equipment Or Engine	6. Model Designation And Model No. J57-P-20	7. Nomenclature Engine	8. Serial No. 69461	9. Time Meter Read./Logbook Time or Events (if applicable): Hour meter; Logbook hrs. 720; Starts; Landings
Unit, Component Accessory, Assembly Or Equipage	10. Manufacturer's Part No. 32164-000	11. Nomenclature Generator Tachometer	12. Serial No. 7218	13. Mfr's Code No. 80247; 14. Contract No. N383-14062; 15. Time Or Events: Hrs. 293; Starts; Ldg's
Subassembly (Electronic) Or Primary Part Failure (Non-electronic)	16. Manufacturer's Part No.	17. Nomenclature	18. Serial No.	19. Mfr's Code No.; 20. Location (if applicable)
Supply Identification Item(s) Returned	21. Federal Stock Number RH6685-203-2043VGCJ	22. (RM, MR copies only)	23. Quantity 1 Each	24. (RM, MR copies only); 25. (RM, MR copies only)

Reason For Report (Check one) — 26. Removal Or Maintenance Action Required As A Result Of:
1 [X] Failure/Suspected Failure Or malfunction; 2 [ ] Damaged due To improper Maintenance/Operation/Test; 3 [ ] Damaged or Defective On receipt; 4 [ ] Damaged Accidentally; 5 [ ] Scheduled/Directed Removal, high time Overage, excess To requirements

27. Item overhauled by

DESCRIPTION OF TROUBLE
(If box 1, 2, 3, or 4 was checked in space 26, complete spaces 28 through 31. If box 5 was checked in space 26, leave spaces 28 through 31 blank.)

28. First Observed/Occurred During

1 [ ] Flight operations—Land based	3 [ ] Pre-flight	5 [ ] Conditional	7 [ ] Overhaul/PAR	9 [ ] Special directed inspection
2 [X] Flight operations carrier based	4 [ ] Daily	6 [ ] Calendar	8 [ ] Shop maintenance bench test	10 [ ] Normal operation of support equip., catapults, arresting gear, mirror landing sys. only.

29. Symptoms—How Discovered (Item)

	D [ ] Incorrect display	I [ ] Low performance	N [ ] Overheating	
	E [ ] Inoperative	J [ ] Metal in oil	O [ ] Pressure out-of-limits	S [ ] Torque out-of-limits
A [ ] Excessive vibration	F [ ] Interference/Binding	K [ ] Noisy	P [ ] RPM out-of-limits	T [ ] Unstable operation
B [ ] High fuel consumption	G [ ] Intermittent operation	L [ ] None noticed	Q [X] Surging/Fluctuates	U [ ] Visible defect
C [ ] High oil consumption	H [ ] Leakage	M [ ] Out-of-balance	R [ ] Temperature out-of-limits	V [ ] Other (Amplify)

30. Part Condition

				585 [ ] Sheared
007 [ ] Arced	130 [ ] Changed value	201 [ ] Distorted/Stretched	750 [ ] Missing	196 [ ] Shorted/Grounded
780 [ ] Bent	910 [ ] Chipped/Nicked	148 [ ] Eroded	008 [ ] Noisy	422 [ ] Soldering defect
135 [ ] Binding	999 [ ] Circuit defective	250 [ ] Frayed/Torn	450 [ ] Open	660 [ ] Stripped
429 [ ] Blistered/Peeled	160 [ ] Connections defective	001 [ ] Gassy	790 [ ] Out-of-adjustment	018 [ ] Tested OK—Did not work
070 [ ] Broken/Cracked	818 [ ] Contacts Burned/Pitted	381 [ ] Leaking	439 [ ] Plugged/Clogged	389 [X] Unknown (Cannot disassemble)
900 [ ] Burned/Burned out	170 [ ] Corroded	730 [ ] Loose	576 [ ] Ruptured/Split/Blown	020 [ ] Worn—Excessively
120 [ ] Chafed/Galled	200 [ ] Dented	004 [ ] Low GM or emission	935 [ ] Scored	099 [ ] Other (Amplify)

31. Cause Of Trouble

A [ ] Design deficiency	D [ ] Faulty overhaul (Quality control)	G [ ] Fluid contamination	J [ ] Operator technique/Adjustment	M [ ] Weather conditions
B [ ] Faulty maintenance (Quality Control)	E [ ] Faulty preservation/Packaging	H [ ] Installation environment (Location in weapons sys.)	K [ ] Other parts primary cause	N [ ] Wrong part installation
C [ ] Faulty manufacturing (Quality Control)	F [ ] Foreign object	I [ ] No failure-replaced to improve sys. performance	L [X] Undetermined (Cannot disassemble)	O [ ] Other (Amplify)

32. DISPOSITION OR CORRECTIVE ACTION: Select appropriate code(s) from list below and enter in boxes at left to indicate disposition or corrective action taken with respect to each of the items entered in spaces 6, 10, and 16.

Space 6 [ ]
Space 10 [F]
Space 16 [ ]

Replaced And Returned To Supply

Code	Reason
A	Hold 90 days
B	Lack of repair facilities
C	Lack of repair parts
D	Lack of Tech. Pubs.
E	Lack of personnel
F	Beyond assigned maintenance level
G	Other—(Defective on receipt, high time, directed removal, excess to requirements, etc.)

Code	Corrective Action
H	Used as is
I	Adj./Realign./Serv./Repaired in place
J	Removed-Adj./Realign./Serv./Repaired-reinstalled
K	Removed-repaired-made RFI
L	Removed-tested Ok-made RFI
M	Removed-scrapped
N	Surveyed
O	Released for investigation and replaced (Indicate custody in space 35)

33. Maintainability Information

	Hours	Tenths
Man-hours to locate trouble Space 10	1	
Man-Hours to locate trouble Space 16		
Man-hours to repair/replace/adjust	1	
Actual time A/C was undergoing repair	2	
Total time aircraft not flyable due to this malfunction	2	5

ACCESSIBILITY: S [X] Satisfactory; U [ ] Unsatisfactory (Amplify)
SPECIAL: 1 [X] Frequent trouble item; 2 [ ] Can be installed wrong (Amplify)

34. Component/Assembly, Subassembly Replaced With:
Mfr's Part No. 32164-000
Serial No. 7934
Mfr's Code No. 80247

35. AMPLIFYING REMARKS (Furnish additional information concerning failure or corrective action not covered above. Do not merely repeat information checked above. Specify any severe operating conditions, such as hard landings, wheels-up landings, severe maneuvers, etc.)

36. Report Is: 0 [X] FUR; 1 [ ] AMPFUR; 2 [ ] Urgent AMPFUR; 3 [ ] Flight Safety AMPFUR; 4 [ ] Follow up report

Signature: S Srednya — Rank/Rate: AECM — Date: 5-16-65

Associated Parts Repaired Or Replaced (Do not list any item reported above)	37. Part No. (Non-electronic parts) Or Part Ref. Designator (Electronic parts)	38. Part Name, Tube Type, Semi-Conductor Type Or Description	39. Mfr's Code No.	40. Failure Code (From space 30)	41. Disposition (Code from space 32)	42. Activity Repaired By
						Signature
						Rank/Rate; Date

FAILURE, UNSATISFACTORY OR REMOVAL REPORT
NAVWEPS FORM 13070/3 (10-62) — (Mail this copy to NATSF) — FUR

Figure 24-6.—Completed FUR (NavWeps 13070/3).

group of the message is reported under "Amplifying Remarks."

FLIGHT SAFETY AMPFUR is the highest priority report and should be indicated for those conditions where personnel or aircraft safety is involved. This category report receives priority processing and evaluation. In addition, a FLIGHT SAFETY AMPFUR message is submitted for each situation resulting in the origination of a FLIGHT SAFETY AMPFUR. A copy of these messages is also sent to the cognizant Bureau of Naval Weapons Fleet Readiness Representative.

In each case of FUR preparation, the category and priority determination is the responsibility of the originating activity. Amplified reports are required in all cases wherein cause of damage or failure cannot be ascertained and/or may be recurrent in other aircraft.

After preparation, all reports are reviewed by a designated maintenance supervisor prior to release to assure completeness, accuracy, and legibility of all parts of the FUR set. Copies of all FUR's are maintained in the originating activity's files for not less than 6 months. FUR files are subject to administrative inspections.

Information is entered on the FUR forms with a typewriter or ballpoint pen to insure that all copies are legible. Reports should be completed in accordance with the instructions included with each set or group of report forms, and all available data should be furnished.

Submission of FUR Form

URGENT and FLIGHT SAFETY AMPFUR's are mailed the same day the deficient condition is discovered. When the defective parts are delivered to an AMD and repairs cannot be made immediately, the original report is mailed to the Naval Air Technical Services Facility, and the AMD submits a FOLLOWUP report upon completion of repairs.

FUR and AMPFUR reports are mailed to the Naval Air Technical Services Facility immediately upon completion of service or repair action by the squadron or the AMD as appropriate. When repairs are beyond the capability of the AMD, the report is completed to show the disposition and then mailed.

Continental activities east of the Mississippi River mail FUR's by regular mail. All activities west of the Mississippi River and outside the continental limits forward reports by airmail. Mailing envelopes are addressed as follows:

Naval Air Technical Services
Facility (MR),
700 Robbins Ave.,
Philadelphia, Pa. 19111

Normally, items reported by the FUR system are unclassified and only in cases where restricted modes of operation or frequencies are a part of the comments will classification be required. Where there is any question as to need for classification, then the current BuWeps security classification guides are applied and classified reports are forwarded in accordance with the U. S. Navy Security Manual. Whenever possible, classified information should be submitted as an enclosure to the report, thereby permitting ultimate removal and declassification of the basic report.

Enclosures consisting of extensive narrative or engineering remarks may be prepared on plain bond paper and attached to the AMPFUR as a continuation of the Amplifying Remarks. Photographs, drawings, or sketches should be attached to the AMPFUR when the addition of such matter will assist in evaluating the cause of the deficiencies. Photographs should preferably be 8- by 10-inch glossy prints and should include at least one detail photograph and one showing the general area (3 copies of each) in which the failure occurred. All enclosures should note the reporting activity and the AMPFUR serial number. Samples of failed material should not be forwarded with the FUR or AMPFUR.

FUR Data Processing

The large volume of reports submitted to the reports processing center under this program makes it impractical to review or analyze all of the reports individually. Therefore, the majority of failure reports received are processed by automatic data processing methods. This machine processing is accomplished in several different forms, each of which is designed to serve a specific user or requirement. The various methods of using or assembling failure data are described in the following paragraphs.

Punched cards are prepared for each report submitted and contain all essential information from the reports. Punched cards are used in preparing various tabulations and to serve as a permanent file for researching historical data and for special studies. Duplicates of these cards are also distributed to various users. All reports

containing narrative information and/or enclosures are additionally reproduced into a microfilm form which is inserted into special punched cards for use by contractors, vendors, and Overhaul and Repair Departments. These film and punch card sets enable users to provide detailed review and analyses as to causes of failure and to determine the appropriate corrective action. From this it can be readily seen that all errors or omissions on the original report will also appear on the microfilm copy.

All amplified reports received at the Naval Air Technical Services Facility are screened by technical personnel. In the case of priority reports (Urgent AMPFUR or Flight Safety AMPFUR), a fascimile of the report is made and forwarded to the cognizant technical division in BuWeps. Amplified nonpriority reports (AMPFUR's) containing information considered to be of special interest to BuWeps, are also processed in a similar manner. Whenever reports are received which indicate faulty manufacturing, faulty preservation, or packing deficiencies, copies of these reports are made and promptly forwarded to the Aviation Supply Office and the Quality Control and Field Administration Division of BuWeps for investigation, as appropriate. When appropriate, an additional copy is also forwarded to the cognizant Material Inspection Service Office.

Tabulations are prepared monthly on all reports received during the calendar month. These tabulations are prepared in various formats designed to be of most service to the users of specific types of data. For example, all reports which indicate the item has been previously overhauled are tabulated and distributed to overhaul activities for quality control purposes. Additional special reports are prepared upon request of activities when specific failure data are necessary to conduct detailed studies.

The Bureau of Naval Weapons Aeronautical Material Reliability Digest is a monthly newsletter type publication designed to provide feedback information to the operating activities concerning BuWeps or contractor action on reported troubles. The Digest also lists excerpts from Flight Safety AMPFUR's and Urgent AMPFUR's that were recently submitted and on which BuWeps action is not yet complete. In addition, the cover letter of each issue is used to discuss particular trouble areas or to provide special instructions for more effective application of malfunction reporting.

In addition to the technical information provided in the Digest, two copies of an illustrated training poster entitled "FUR Example" are enclosed. These posters usually emphasize some facet of the Malfunction Reporting Program. When actual examples of FUR's are illustrated in these posters, they highlight areas in which mistakes have been made or insufficient information has been provided by originating activities.

USAGE DATA REPORTS

The Usage Data Report is a part of the Maintenance Usage Data Program. The purpose of this program is to aid the Aviation Supply Office in determining probable future usage of aeronautic materials. The important part that accurate and timely usage data plays in the material support of the Navy's aeronautic program cannot be overemphasized. The lack of usage data has been a basic cause of many of the critical material shortages in the support program. Only accurate and timely reporting by all maintenance activities can reduce to a minimum the element of guesswork in determining material requirements.

Each shop is required to keep a daily usage record and turn it in to the maintenance office at the end of each month. The daily record may be kept by using copies of the requisition form (DD Form 1348) of material placed on order. The use of DD Form 1348 reduces the probability of reporting usage twice (once when the demand occurs, and then again when the demand is satisfied).

When an item is used but was not obtained through routine supply channels, a usage stub must be prepared to record the demand for the item, and the usage stub must be filed in the maintenance usage file. This includes items obtained through O&R customer service, contractor's representatives, Air Force, salvage, cannibalization, other squadrons, etc.

It should be kept in mind that only items removed and replaced should be included in the maintenance data report. For example, when an assembly or subassembly is removed and repaired locally, the report should not indicate usage of the assembly or subassembly as such, but should indicate only the parts used in making the repair.

ALLOWANCE LISTS

Allowance Lists consist of listings of the equipment and material necessary to place and maintain vehicles and aircraft in a material readiness condition. These allowances are based on known or estimated requirements or on available usage data.

Allowance lists are identified by sections. Certain sections such as R, X, G, B, and T are of particular interest to the AE, and he should become familiar with their contents and use.

Section R

Section R is a series of publications issued for specific squadrons, vessels, units, or other activities engaged in the support and operation of aviation electrical and electronic equipment.

These lists indicate allowances of electrical/electronic material and associated test equipment, as well as the material required by maintenance and operating activities for the support of installed aeronautic electrical and electronic equipment. The Initial Outfitting List (NavWeps 00-35QR-7) is a listing of equipment requiring electron tube support.

Section X

This listing sets forth allowances of avionics support equipment required by maintenance activities for support of instrument and armament control systems installed in naval aircraft. These allowance lists include such items as: Autopilot and stabilization systems, compass systems, fuel quantity systems, etc.

Section G

This allowance list contains allowances of shop and general support equipment and material which is for maintenance support of aircraft which may be assigned or supported by aircraft maintenance activities. This list includes such items as battery charger, motor generator drive sets, growlers, and handtools.

Section B

This list is compiled and distributed by BuWeps and contains supply items which have the greatest turnover for a certain type of aircraft. According to the number of aircraft assigned to a particular squadron, the Section B allowance list gives the quantity of certain types of parts which this squadron might expect to use over a 90-day period. It also shows how many of certain parts or components are used on a single aircraft. From the standpoint of ordering parts, the Section B allowance list is most useful because it gives ordering information for all items listed. Its greatest limitation is that it lists relatively few of all the parts on an aircraft. The AE will become more familiar with its contents by using it. After repeated usage, he will often know, without looking, which items appear in the Section B allowance list and which ones do not.

Section T

The purpose of this list is to set forth allowances of special engine tools required for maintenance support of aircraft engines assigned to the squadron or maintenance activity and support of particular aircraft. For example, NavWeps 00-35QT-10 is the allowance for special maintenance support equipment for Douglas aircraft, and includes part numbers and stock numbers for certain special electric test equipment such as the cabin pressure amplifier tester.

APPENDIX I

ELECTRICAL AND ELECTRONIC TERMS

AGONIC.—An imaginary line of the earth's surface passing through points where the magnetic declination is 0°; that is, positions where the compass points to true north.

AMMETER.—An instrument for measuring the amount of electron flow in amperes.

AMPERE.—The basic unit of electrical current.

AMPERE-TURN.—The magnetizing force produced by a current of one ampere flowing through a coil of one turn.

AMPLIFICATION.—The process of increasing the strength (current, power, or voltage) of a signal.

AMPLIFIER.—A device used to increase the signal voltage, current, or power, generally composed of a vacuum tube and associated circuit called a stage. It may contain several stages in order to obtain a desired gain.

AMPLITUDE.—The maximum instantaneous value of an alternating voltage or current, measured in either the positive or negative direction.

ARC.—A flash caused by an electric current ionizing a gas or vapor.

ARMATURE.—The rotating part of an electric motor or generator. The moving part of a relay or vibrator.

AUTOTRANSFORMER.—A transformer in which the primary and secondary are connected together in one winding.

BATTERY.—Two or more primary or secondary cells connected together electrically. The term does not apply to a single cell.

BIAS.—Vacuum tube—the difference of potential between the control grid and the cathode; transistor—the difference of potential between the base and emitter, and the base and collector; magnetic amplifier—the level of flux density in the magnetic amplifier core under no-signal condition.

BIAS WINDING.—The winding on the core of a magnetic amplifier that controls the bias.

BREAKER POINTS.—Metal contacts that open and close a circuit.

BRUSH.—The conducting material, usually a block of carbon, bearing against the commutator or sliprings through which the current flows in or out.

BUS BAR.—A primary power distribution point connected to the main power source.

CAPACITOR.—Two electrodes or sets of electrodes in the form of plates, separated from each other by an insulating material called the dielectric.

CATHODE.—The electrode in a vacuum tube which is the source of electron emission; also a negative electrode.

CHOKE COIL.—A coil of low ohmic resistance and high impedance to alternating current.

CIRCUIT.—The complete path of an electric current.

CIRCUIT BREAKER.—An electromagnetic or thermal device that opens a circuit when the current in the circuit exceeds a predetermined amount. Circuit breakers can be reset.

CIRCULAR MIL.—An area equal to that of a circle with a diameter of 0.001 inch. It is used for measuring the cross section of wires.

COAXIAL CABLE.—A transmission line consisting of two conductors concentric with and insulated from each other.

COMMUTATOR.—The copper segments on the armature of a motor or generator. It is cylindrical in shape and is used to pass power into or from the brushes. It is a switching device.

CONDUCTANCE.—The ability of a particular sample of a substance to conduct or carry an electric current. It is the reciprocal of the resistance of the sample, and is expressed in mhos.

CONDUCTIVITY.—The ease with which a substance (in general, rather than a specific sample) transmits electricity.

CONDUCTOR.—Any material suitable for carrying electric current.

CORE.—A magnetic material that affords an easy path for magnetic flux lines in a coil.

COUNTER E.M.F.—Counter electromotive force; an e.m.f. induced in a coil or armature that opposes the applied voltage.

CURRENT LIMITER.—A protective device similar to a fuse, usually used in high amperage circuits.

CYCLE.—One complete positive and one complete negative alternation of a current or voltage.

DIELECTRIC.—An insulator; a term that refers to the insulating material between the plates of a capacitor.

DIODE.—Vacuum tube—a two element tube that contains a cathode and plate; semiconductor—a material of either germanium or silicon that is manufactured to allow current to flow in only one direction. Diodes are used as rectifiers and detectors.

DIRECT CURRENT.—An electric current that flows in one direction only.

EDDY CURRENT.—Induced circulating currents in a conducting material that are caused by a varying magnetic field.

EFFICIENCY.—The ratio of output power to input power, generally expressed as a percentage.

ELECTROLYTE.—A solution of a substance which is capable of conducting electricity. An electrolyte may be in the form of either a liquid or a paste.

ELECTROMAGNET.—A magnet made by passing current through a coil of wire wound on a soft iron core.

ELECTROMOTIVE FORCE (e.m.f.).—The force that produces an electric current in a circuit.

ELECTRON.—A negatively charged particle of matter.

ENERGY.—The ability or capacity to do work.

FARAD.—The unit of capacitance.

FEEDBACK.—A transfer of energy from the output circuit of a device back to its input.

FIELD.—The space containing electric or magnetic lines of force.

FIELD WINDING.—The coil used to provide the magnetizing force in motors and generators.

FLUX FIELD.—All electric or magnetic lines of force in a given region.

FREE ELECTRONS.—Electrons which are loosely held and consequently tend to move at random among the atoms of the material.

FREQUENCY.—The number of complete cycles per second existing in any form of wave motion; such as the number of cycles per second of an alternating current.

FULL-WAVE RECTIFIER CIRCUIT.—A circuit which utilizes both the positive and the negative alternations of an alternating current to produce a direct current.

FUSE.—A protective device inserted in series with a circuit. It contains a metal that will melt or break when current is increased beyond a specific value for a definite period of time.

GAIN.—The ratio of the output power, voltage, or current to the input power, voltage, or current, respectively.

GALVANOMETER.—An instrument used to measure small d-c currents.

GAS TUBE.—A tube that has certain electrical characteristics because it is filled with a certain type of gas.

GENERATOR—A machine that converts mechanical energy into electrical energy.

GRID.—A wire, usually in the form of a spiral, that controls the electron flow in a vacuum tube.

GRID LEAK.—A high resistance connected across the grid capacitor or between the grid and the cathode to provide a d-c path from grid to cathode and to limit the accumulation of charge on the grid.

GROUND.—A metallic connection with the earth to establish ground potential. Also, a common return to a point of zero potential. The chassis of a receiver or a transmitter is sometimes the common return, and therefore the "ground" of the unit.

HENRY.—The basic unit of inductance.

HOLE.—In semiconductors, the space in an atom left vacant by a departed electron.

HORSEPOWER.—The English unit of power, equal to work done at the rate of 550 foot-pounds per second. Equal to 746 watts of electrical power.

HYSTERESIS.—A lagging of the magnetic flux in a magnetic material behind the magnetizing force which is producing it.

IMPEDANCE.—The total opposition offered to the flow of an alternating current. It may consist of any combination of resistance, inductive reactance, and capacitive reactance.

INDUCTANCE.—The property of a circuit which tends to oppose a change in the existing current.

INDUCTION.—The act or process of producing voltage by the relative motion of a magnetic field across a conductor.

INDUCTIVE REACTANCE.—The opposition to the flow of alternating or pulsating current caused by the inductance of a circuit. It is measured in ohms.

INPHASE.—Applied to the condition that exists when two waves of the same frequency pass through their maximum and minimum values of like polarity at the same instant.

ISOGONIC LINE.—An imaginary line drawn through points on the earth's surface where the magnetic variation is equal.

JOULE.—A unit of energy or work. A joule of energy is liberated by one ampere flowing for one second through a resistance of one ohm.

KILO.—A prefix meaning 1,000.

LAG.—The amount by which one wave is behind another in time; expressed in electrical degrees.

LAMINATED CORE.—A core built up from thin sheets of metal and used in transformers and relays.

LEAD.—The opposite of lag. Also, a wire or connection.

LINE OF FORCE.—A line in an electric or magnetic field that shows the direction of the force.

LOAD.—The power that is being delivered by any power producing device. The equipment that uses the power from the power producing device.

MAGNETIC AMPLIFIER.—A saturable reactor type device that is used in a circuit to amplify or control.

MAGNETIC CIRCUIT.—The complete path of magnetic lines of force.

MAGNETIC FIELD.—The space in which a magnetic force exists.

MAGNETIC FLUX.—The total number of lines of force issuing from a pole of a magnet.

MAGNETIZE.—To convert a material into a magnet by causing the molecules to rearrange themselves.

MAGNETO.—A generator which produces alternating current and has a permanent magnet as its field.

MEGGER.—A test instrument used to measure insulation resistance and other high resistances. It is a portable hand-operated d-c generator used as an ohmmeter.

MEGOHM.—A million ohms.

MICRO.—A prefix meaning one-millionth.

MILLI.—A prefix meaning one-thousandth.

MILLIAMMETER.—An ammeter that measures current in thousandths of an ampere.

MOTOR-GENERATOR.—A motor and a generator with a common shaft used to convert line voltages to other voltages or frequencies.

MUTUAL INDUCTANCE.—A circuit property existing when the relative position of two inductors causes the magnetic lines of force from one to link with the turns of the other.

NEGATIVE CHARGE.—The electrical charge carried by a body which has an excess of electrons.

NEUTRON.—A particle having the weight of a proton but carrying no electric charge. It is located in the nucleus of an atom.

NUCLEUS.—The central part of an atom that comprises protons and neutrons. It is the part of the atom that has the most mass.

NULL.—Zero or minimum.

OHM.—The unit of electrical resistance.

OHMMETER.—An instrument for directly measuring resistance in ohms.

OVERLOAD.—A load greater than the rated load of an electrical device.

PERMALLOY.—An alloy of nickel and iron having an abnormally high magnetic permeability.

PERMEABILITY.—A measure of the ease with which magnetic lines of force can flow through a material as compared to air.

PHASE DIFFERENCE.—The time in electrical degrees by which one wave leads or lags another.

PLATE.—The principal electrode in a tube to which the electron stream is attracted.

PLATE CURRENT.—The current flowing in the plate circuit of a vacuum tube.

POLARITY.—The character of having magnetic poles, or electric charges.

POLE.—The section of a magnet where the flux lines are concentrated; also where they enter and leave the magnet. An electrode of a battery.

POLYPHASE.—A circuit that utilizes more than one phase of alternating current.

POSITIVE CHARGE.—The electrical charge carried by a body which has become deficient in electrons.

POTENTIAL.—The amount of charge held by a body as compared to another point or body. Usually measured in volts.

POTENTIOMETER.—A variable voltage divider; a resistor which has a variable contact arm so that any portion of the potential applied between its ends may be selected.

POWER.—The rate of doing work or the rate of expending energy. The unit of electrical power is the watt.

POWER FACTOR.—The ratio of the actual power of an alternating or pulsating current, as measured by a wattmeter, to the apparent power, as indicated by ammeter and voltmeter readings. The power factor of an inductor, capacitor, or insulator is an expression of their losses.

PRIME MOVER.—The source of mechanical power used to drive the rotor of a generator.

PROTON.—A positively charged particle in the nucleus of an atom.

RATIO.—The value obtained by dividing one number by another, indicating their relative numerical size.

REACTANCE.—The opposition offered to the flow of an alternating current by the inductance, capacitance, or both, in any circuit.

RECTIFIERS.—Devices used to change alternating current to unidirectional current. These may be vacuum tubes, semiconductors such as germanium and silicon, dry-disk rectifiers such as selenium and copper-oxide, and certain other types of crystal.

RELAY.—An electromechanical switching device that can be used as a remote control.

RELUCTANCE.—A measure of the opposition that a material offers to magnetic lines of force.

RESISTANCE.—The opposition to the flow of current caused by the nature and physical dimensions of a conductor.

RESISTOR.—A circuit element whose chief characteristic is resistance; used to oppose the flow of current.

RESONANCE.—The condition existing in a circuit in which the inductive and capacitive reactances cancel each other.

RETENTIVITY.—The measure of the ability of a material to hold its magnetism.

RHEOSTAT.—A variable resistor.

SATURABLE REACTOR.—A control device that uses a small d-c current to control a large a-c current by controlling core flux density.

SATURATION.—The condition existing in any circuit when an increase in the driving signal produces no further change in the resultant effect.

SELF-INDUCTION.—The process by which a circuit induces an e.m.f. into itself by its own magnetic field.

SERIES-WOUND.—A motor or generator in which the armature is wired in series with the field winding.

SERVO.—A device used to convert a small movement into one of greater movement or force.

SERVOMECHANISM.—A closed-loop system that produces a force to position an object in accordance with the information that originates at the input.

SOLENOID,—An electromagnetic coil that contains a movable plunger.

SPACE CHARGE.—The cloud of electrons existing in the space between the cathode and plate in a vacuum tube, formed by the electrons emitted from the cathode in excess of those immediately attracted to the plate.

SYNCHRO SYSTEM.—An electrical system that gives remote indications or control by means of self-synchronizing motors.

TACHOMETER.—An instrument for indicating revolutions per minute.

TEMPERATURE COEFFICIENT.—A number indicating the variation of resistance in a conductor due to temperature change.

TERTIARY WINDING.—A third winding on a transformer or magnetic amplifier. In the magnetic amplifier it is used as a second control winding.

THERMISTOR.—A resistance element that is used to compensate for temperature variations in a circuit. It is made of a semiconducting material which exhibits a NEGATIVE temperature coefficient of resistivity. The resistance decreases as the temperature increases.

THERMOCOUPLE.—A junction of two dissimilar metals that produces a voltage when heated.

TRANSFORMER.—A device composed of two or more coils, linked by magnetic lines of force, used to transfer energy from one circuit to another.

TRANSMISSION LINE.—Any conductor or system of conductors used to carry electrical energy from its source to a load.

TRIODE.—A three-electrode vacuum tube, containing a cathode, control grid, and plate.

TUNED CIRCUIT.—A resonant circuit.

VACUUM TUBE.—An evacuated envelope c
taining two or more electrodes.

VECTOR.—A line used to represent both di
tion and magnitude.

VOLT.—The unit of electrical potential.

WATT.—The unit of electrical power.

WATTMETER.—An instrument for measu
electric power in watts.

APPENDIX II

FORMULAS

Ohm's Law for D-C Circuits

$$I = \frac{E}{R} = \frac{P}{E} = \sqrt{\frac{P}{R}}$$

$$R = \frac{E}{I} = \frac{P}{I^2} = \frac{E^2}{P}$$

$$E = IR = \frac{P}{I} = \sqrt{PR}$$

$$P = EI = \frac{E^2}{R} = I^2R$$

Resistors in Series

$$R_T = R_1 + R_2 + \ldots$$

Resistors in Parallel

Two resistors

$$R_T = \frac{R_1R_2}{R_1 + R_2}$$

More than two

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots$$

RL Circuit Time Constant

$$\frac{L \text{ (in henrys)}}{R \text{ (in ohms)}} = t \text{ (in seconds), or}$$

$$\frac{L \text{ (in microhenrys)}}{R \text{ (in ohms)}} = t \text{ (in microseconds)}$$

RC Circuit Time Constant

R (ohms) x C (farads) = t (seconds)

R (megohms) x C (microfarads) = t (seconds)

R (ohms) x C (microfarads) = t (microseconds)

R (megohms) x C (micromicorfarads) = t (microseconds)

Capacitors in Series

Two capacitors

$$C_T = \frac{C_1C_2}{C_1 + C_2}$$

More than two

$$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \ldots$$

Capacitors in Parallel: $C_T = C_1 + C_2 + \ldots$

Capacitive Reactance: $X_C = \frac{1}{2\pi fC}$

Impedance in an RC Circuit (Series)

$$Z = \sqrt{R^2 + (X_C)^2}$$

Inductors in Series

$L_T = L_1 + L_2 + \ldots$ (No coupling between coils)

Inductors in Parallel

Two inductors

$L_T = \frac{L_1L_2}{L_1 + L_2}$ (No coupling between coils)

More than two

$\frac{1}{L_T} = \frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3} + \ldots$ (No coupling between coils)

Inductive Reactance

$$X_L = 2\pi fL$$

Q of a Coil

$$Q = \frac{X_L}{R}$$

Impedance of an RL Circuit (Series)

$$Z = \sqrt{R^2 + (X_L)^2}$$

Impedance with R, C, and L in Series

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

Parallel Circuit Impedance

$$Z = \frac{Z_1 Z_2}{Z_1 + Z_2}$$

Sine-Wave Voltage Relationships

Average value

$$E_{ave} = \frac{2}{\pi} \times E_{max} = 0.637E_{max}$$

Effective or r. m. s. value

$$E_{eff} = \frac{E_{max}}{\sqrt{2}} = \frac{E_{max}}{1.414} = 0.707E_{max}$$

$$= 1.11E_{ave}$$

Maximum value

$$E_{max} = \sqrt{2}\,(E_{eff}) = 1.414E_{eff} = 1.57E_{ave}$$

Voltage in an a-c circuit

$$E = IZ = \frac{P}{I \times P.F.}$$

Current in an a-c circuit

$$I = \frac{E}{Z} = \frac{P}{E \times P.F.}$$

Power in A-C Circuit

Apparent power: $P = EI$

True power: $P = EI \cos \phi = EI \times P.F.$

Power Factor

$$P.F. = \frac{P}{EI} = \cos \phi$$

$$\cos \phi = \frac{\text{true power}}{\text{apparent power}}$$

Transformers

Voltage relationship

$$\frac{E_p}{E_s} = \frac{N_p}{N_s} \text{ or } E_s = E_p \times \frac{N_s}{N_p}$$

Current relationship

$$\frac{I_p}{I_s} = \frac{N_s}{N_p}$$

Induced voltage

$$E_{eff} = 4.44 \times BAfN \times 10^{-8}$$

Turns ratio

$$\frac{N_p}{N_s} = \sqrt{\frac{Z_p}{Z_s}}$$

Secondary current

$$I_s = I_p \times \frac{N_p}{N_s}$$

Secondary voltage

$$E_s = E_p \times \frac{N_s}{N_p}$$

Three-Phase Voltage and Current Relationships

With Wye connected windings

$$E_{line} = \sqrt{3}(E_{coil}) = 1.732E_{coil}$$

$$I_{line} = I_{coil}$$

With delta connected windings

$$E_{line} = E_{coil}$$

$$I_{line} = 1.732I_{coil}$$

With wye or delta connected winding

$$P_{coil} = E_{coil} I_{coil}$$

$$P_t = 3P_{coil}$$

$$P_t = 1.732E_{line} I_{line}$$

(To convert to true power multiply by $\cos\phi$)

Resonance

At resonance

$$X_L = X_C$$

Resonant frequency

$$F_o = \frac{1}{2\pi\sqrt{LC}}$$

Series resonance

$$Z \text{ (at any frequency)} = R + j(X_L - X_C)$$

$$Z \text{ (at resonance)} = R$$

Parallel resonance

$$Z \text{ (at any frequency)} = \frac{Z_1 Z_2}{Z_1 + Z_2}$$

$$Z_{max} \text{ (at resonance)} = \frac{X_L X_C}{R} = \frac{X_L{}^2}{R} = QX_L$$

$$= \frac{L}{CR}$$

Band width

$$\Delta = \frac{F_o}{Q} = \frac{R}{2\pi L}$$

Tube Characteristics

Amplification factor

$$\mu = \frac{\Delta e_p}{\Delta e_g} \text{ (}i_p\text{ constant)}$$

$$\mu = g_m r_p$$

A-c plate resistance

$$r_p = \frac{\Delta e_p}{\Delta i_p} \text{ (}e_g\text{ constant)}$$

Grid-plate transconductance

$$g_m = \frac{\Delta i_p}{\Delta e_g} \text{ (}e_p\text{ constant)}$$

Decibels

NOTE: Wherever the expression "log" appears without a subscript specifying the base, the logarithmic base is understood to be 10.

Power ratio

$$db = 10 \log \frac{P_2}{P_1}$$

Current and voltage ratio

$$db = 20 \log \frac{I_2 \sqrt{R_2}}{I_1 \sqrt{R_1}}$$

$$db = 20 \log \frac{E_2 \sqrt{R_1}}{E_1 \sqrt{R_2}}$$

NOTE: When R_1 and R_2 are equal they may be omitted from the formula. When reference level is one milliwatt

$$dbm = 10 \log \frac{P}{0.001} \text{ (when P is in watts)}$$

Synchronous Speed of Motor

$$\text{r.p.m.} = \frac{120 \times \text{frequency}}{\text{number of poles}}$$

Comparison of Units in Electric and Magnetic Circuits

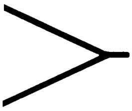
	Electric circuit	Magnetic circuit
Force.	Volt, E, or e.m.f.	Gilberts, F, or m.m.f.
Flow.	Ampere, I	Flux, Φ, in maxwells
Opposition.	Ohms, R	Reluctance, $\mathcal{R}$
Law.	Ohm's law, $I = \frac{E}{R}$	Rowland's law, $\Phi = \frac{F}{\mathcal{R}}$
Intensity of force	Volts per cm. of length.	$H = \frac{1.257IN}{L}$, gilberts per centimeter of length
Density.	Current density--for example, amperes per cm.^{2}	Flux density—for example, lines per cm.^{2}, or gausses

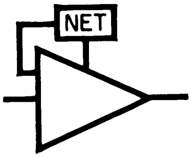
APPENDIX III

ELECTRICAL AND ELECTRONIC SYMBOLS

OURCE

FIER





ANGLE POINTED DIRECTION OF NSMISSION

AMPLIFIER WITH EXTERNAL FEED-BACK PATH

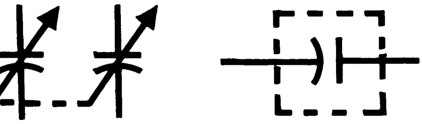
ERIES

CELL MULTICELL TAPPED MULTICELL

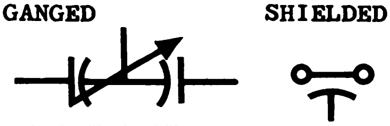
ONG LINE IS ALWAYS POSITIVE)

CITORS

FIXED VARIABLE TRIMMER



GANGED SHIELDED



SPLIT-STATOR FEED-THROUGH

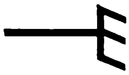
(WHEN CAPACITOR ELECTRODE IDENTIFICATION IS NECESSARY, THE CURVED ELEMENT SHALL REPRESENT THE OUTSIDE ELECTRODE IN FIXED PAPER-DIELECTRIC AND CERAMIC-DIELECTRIC, THE NEGATIVE ELECTRODE IN ELECTROLYTIC CAPACITORS, THE MOVING ELEMENT IN VARIABLE AND ADJUSTABLE CAPACITORS, AND THE LOW POTENTIAL ELEMENT IN FEED-THROUGH CAPACITORS.)

CIRCUIT BREAKERS

SWITCH PUSH-PULL

PUSH

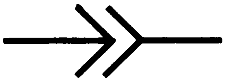
CHASSIS CONNECTION



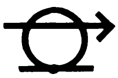
(THE CHASSIS OR FRAME IS NOT NECESSARILY AT GROUND POTENTIAL.)

CONNECTORS

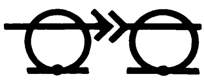
MALE (PIN CONTACT) FEMALE (SOCKET CONTACT)



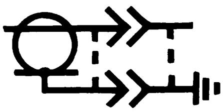
ENGAGED (PIN-TO-SOCKET)



COAXIAL (MALE)



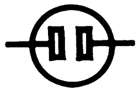
COAXIAL CONNECTORS MATED



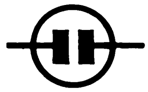
COAXIAL CONNECTED TO SINGLE CONDUCTOR

THE CONNECTOR SYMBOL IS NOT AN ARROWHEAD. IT IS LARGER AND THE LINES ARE DRAWN AT A 90° ANGLE.

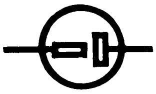
CONNECTORS, POWER



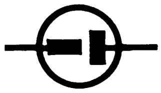
NON POLARIZED, FEMALE CONTACTS (2-CONDUCTOR)



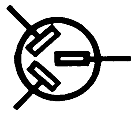
NON POLARIZED, MALE CONTACTS (2-CONDUCTOR)



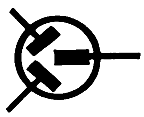
POLARIZED FEMALE CONTACTS (2-CONDUCTOR)



POLARIZED MALE CONTACTS (2-CONDUCTOR)



POLARIZED FEMALE CONTACTS (3-CONDUCTOR)



POLARIZED MALE CONTACTS (3-CONDUCTOR)

CONTACTS

SWITCH

MOMENTARY SWITCH

LOCKING

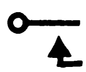
NONLOCKING

 OR  OR 

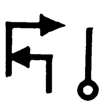
FOR JACK, KEY, RELAY, ETC.

CONTACT ASSEMBLIES

CLOSED CONTACT (BREAK)

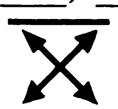


OPEN CONTACT (MAKE)

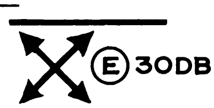


MAKE BEFORE BREAK

COUPLERS, DIRECTIONAL



GENERAL



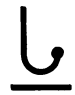
E PLANE APERTURE COUPLING, 30 DB TRANSMISSION LOSS

COUPLING

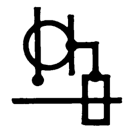
GENERALLY USED FOR COAXIAL AND WAVEGUIDE TRANSMISSION.

COUPLING BY APERTURE WITH AN OPENING OF LESS THAN FULL WAVEGUIDE SIZE. TYPE OF COUPLING WILL BE INDICATED WITHIN CIRCLE (E, H, OR HE).

COUPLING BY LOOP TO SPACE



COUPLING BY LOOP TO GUIDED TRANSMISSION PATH



COUPLING BY PROBE FROM COAXIAL TO RECTANGULAR WAVEGUIDE WITH DIRECT-CURRENT GROUNDS CONNECTED

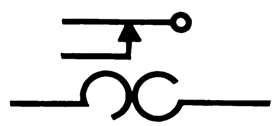
CRYSTAL UNIT

QUARTZ CRYSTAL; PIEZOELECTRIC CRYSTAL UNIT.

DELAY FUNCTION

ELEMENT, THERMAL

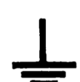
FLASHER; THERMAL CUTOUT



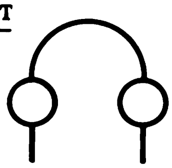
THERMAL RELAY WITH NORMALLY CLOSED CONTACT.

FUSE

GROUND



HEADSET



INDUCTORS

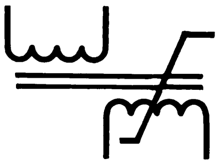
GENERAL

MAGNETIC CORE

TAPPED

ADJUSTABLE

ADJUSTABLE OR CONTINUOUSLY ADJUSTABLE



SATURABLE CORE REACTOR

LIGHT, INDICATING

INDICATING, PILOT, SIGNALING OR SWITCHBOARD PILOT LIGHT, GENERAL.

JEWELLED INDICATOR OR WARNING LIGHT.

A LETTER MAY BE ADDED WITHIN A SYMBOL TO INDICATE A CHARACTERISTIC OR COLOR

METERS

A - AMMETER

CRO - OSCILLOSCOPE

G - GALVANOMETER

MA - MILLIAMMETER

OHM - OHMMETER

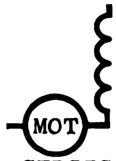
V - VOLTMETER

MOTORS AND GENERATORS

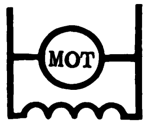
MOTOR

GENERATOR

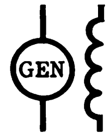
TYPES OF WINDINGS



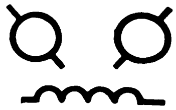
SERIES



SHUNT



SEPARATELY EXCITED



DYNAMOTOR

WINDING SYMBOLS

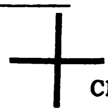
SINGLE-PHASE

TWO - PHASE

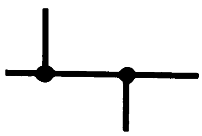
THREE-PHASE (WYE)

THREE-PHASE (DELTA)

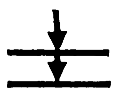
PATH, TRANSMISSION



CROSSING NOT CONNECTED



JUNCTION CONNECTED

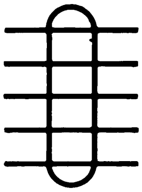


TWISTED PAIR

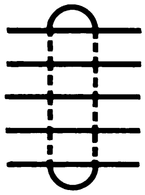
COAXIAL

PATH, TRANSMISSION

CABLES



FIVE-CONDUCTOR CABLE



SHIELDED FIVE-CONDUCTOR CABLE

NUMBER OF CONDUCTORS MAY BE ONE OR MORE AS NECESSARY

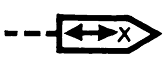
PERMANENT MAGNET

PICKUP HEAD

GENERAL

WRITING; RECORDING; HEAD, SOUND RECORDER

READING; PLAYBACK; HEAD, SOUND REPRODUCER

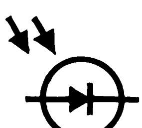


APPLICATION: WRITING, READING, AND ERASING

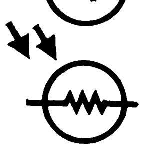
ERASING; ERASER, MAGNETIC

PHOTOELECTRIC CELLS

ASYMMETRICAL PHOTOCONDUCTIVE TRANSDUCER

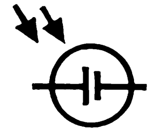


SYMMETRICAL PHOTOCONDUCTIVE TRANSDUCER



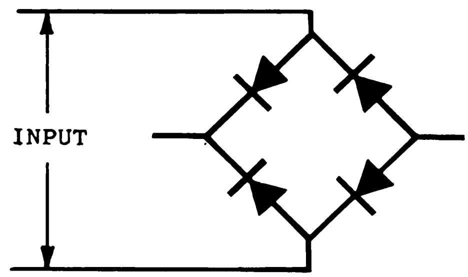
PHOTOELECTRIC CELLS (CONT.)

PHOTOVOLTAIC TRANSDUCER; BARRIER PHOTOCELL; BLOCKING-LAYER CELL; SOLAR CELL



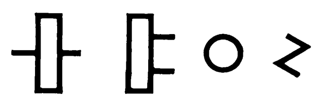
RECTIFIERS

SEMICONDUCTOR DIODE; METALLIC RECTIFIER; ELECTROLYTIC RECTIFIER; ASYMMETRICAL VARISTOR
THE TRIANGLE IN THIS CASE SHALL BE FILLED.

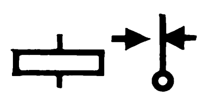


FULL WAVE BRIDGE TYPE

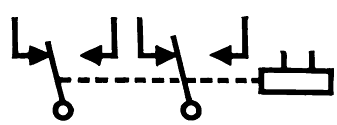
RELAYS



RELAY COIL



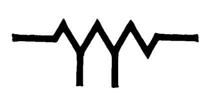
RELAY WITH TRANSFER CONTACTS (SPDT)



DOUBLE POLE, DOUBLE THROW (DPDT) RELAY

RESISTORS

GENERAL

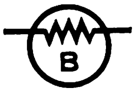


TAPPED

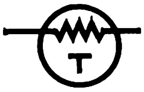
RESISTORS (CONT.)

VARIABLE

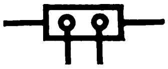
ADJUSTABLE



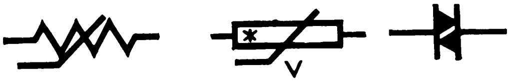
BALLAST LAMP



THERMISTOR

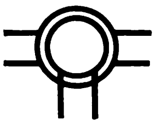


INSTRUMENT OR
RELAY SHUNT

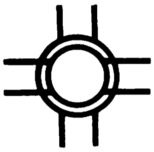


SYMMETRICAL VARISTOR
RESISTOR, VOLTAGE SENSITIVE
(SILICON CARBIDE, ETC.)

RESOLVER (SYNCHRO)

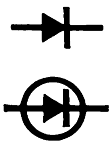


SINGLY-WOUND
ROTOR

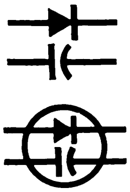


DOUBLY-WOUND
ROTOR

SEMICONDUCTOR DEVICE

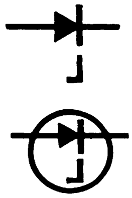


SEMICONDUCTOR DIODE
SEMICONDUCTOR RECTIFIER DIODE

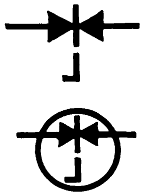


CAPACITIVE DIODE (VARACTOR)

SEMICONDUCTORS (CONT.)

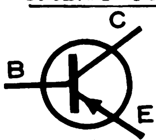


BREAKDOWN DIODE, UNIDIRECTIONAL
(ALSO BACKWARD DIODE)

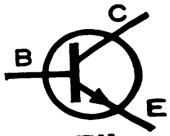


BREAKDOWN DIODE, BIDIRECTIONAL

SEMICONDUCTOR DEVICE,
TRANSISTORS



PNP



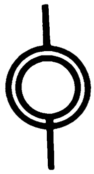
NPN

SHIELDING

SHORT DASHES. NORMALLY
USED FOR ELECTRIC OR MAGNETIC
SHIELDING

SYNCHROS

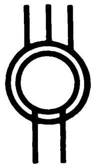
GENERAL



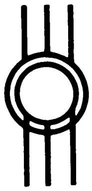
A LETTER COMBINATION FROM THE FOLLOWING LIST MAY BE PLACED ADJACENT TO THE SYMBOL TO INDICATE THE TYPE OF SYNCHRO:

- TX - TORQUE TRANSMITTER
- TDX - TORQUE DIFFERENTIAL TRANSMITTER
- CX - CONTROL TRANSMITTER
- CDX - CONTROL DIFFERENTIAL TRANSMITTER
- TR- TORQUE RECEIVER
- CT - CONTROL TRANSFORMER

SYNCHROS (CONT.)

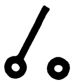


TRANSMITTER, RECEIVER, OR CONTROL TRANSFORMER

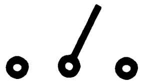


DIFFERENTIAL TRANSMITTER OR RECEIVER

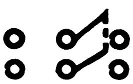
SWITCHES



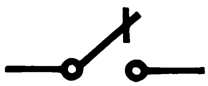
GENERAL (SINGLE THROW)



GENERAL (DOUBLE THROW)

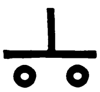


TWO-POLE DOUBLE-THROW SWITCH

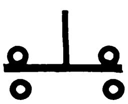


KNIFE SWITCH

PUSH BUTTON (BREAK)

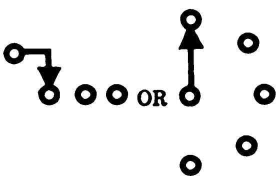


PUSH BUTTON (MAKE)



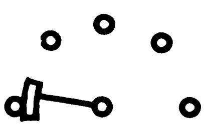
PUSH BUTTON TWO CIRCUIT

SELECTOR SWITCHES

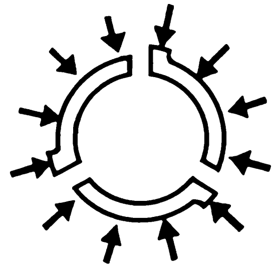


GENERAL
ANY NUMBER OF TRANSMISSION PATHS MAY BE SHOWN. ALSO BREAK-BEFORE-MAKE SWITCH.

MAKE-BEFORE BREAK

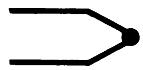


SELECTOR SWITCHES (CONT.)



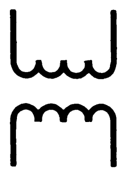
WAFER, TYPICAL 3-POLE, 3-CIRCUIT SWITCH. VIEWED FROM END OPPOSITE CONTROL KNOB. FOR MORE THAN ONE SECTION, #1 IS NEAREST CONTROL KNOB.

THERMOCOUPLES

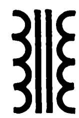


TEMPERATURE-MEASURING THERMOCOUPLE (DISSIMILAR METAL DEVICE)

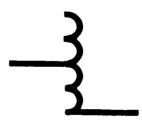
TRANSFORMERS



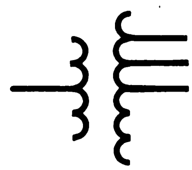
GENERAL



MAGNETIC CORE TRANSFORMER



AUTOTRANSFORMER



WITH TAPS, SINGLE-PHASE

TUBES, ELECTRON

COMPONENT TUBE SYMBOLS

DIRECTLY-HEATED (FILAMENTARY) CATHODE

INDIRECTLY-HEATED CATHODE

GRID

HEATER

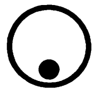
COLD CATHODE

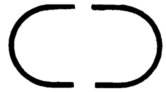
ELECTRON TUBES (CONT)


ANODE OR PLATE

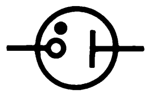

PHOTOCATHODE

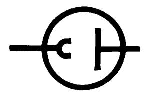
ENVELOPE (SHELL)

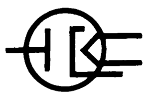

GAS FILLED ENVELOPE

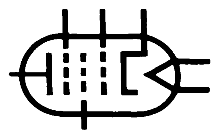

SPLIT ENVELOPE

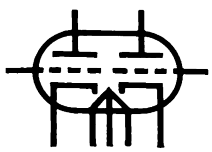
TYPICAL BUILDUP OF TUBE EXAMPLES

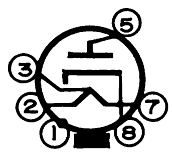

COLD CATHODE GAS TUBE


PHOTOTUBE SINGLE UNIT, VACUUM

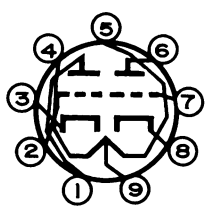

DIODE


PENTODE


TWIN TRIODE ILLUSTRATING ELONGATED ENVELOPE

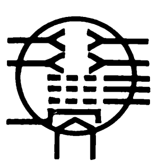


DIODE SHOWING BASE CONNECTIONS

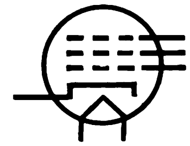


TWIN TRIODE WITH TAPPED HEATER

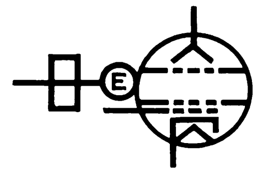
CATHODE RAY TUBE


ELECTROSTATIC DEFLECTION

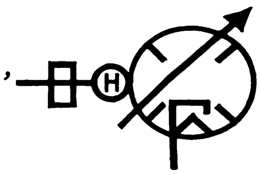
CATHODE RAY TUBE (CONT.)


MAGNETIC DEFLECTION

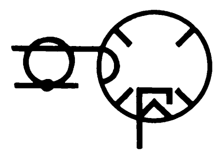
MAGNETRONS AND KLYSTRONS

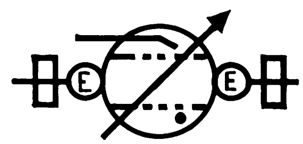


REFLEX KLYSTRON, APERTURE COUPLED



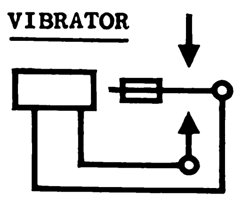
TUNABLE MAGNETRON, APERTURE COUPLED

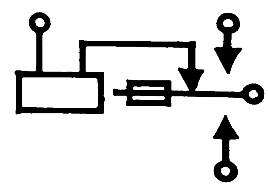

RESONANT TYPE WITH COAXIAL OUTPUT



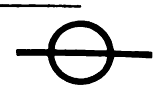
TRANSMIT-RECEIVE (TR) TUBE GAS FILLED, TUNABLE INTEGRAL CAVITY, APERTURE COUPLED, WITH STARTER

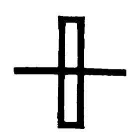
VIBRATOR


TYPICAL, SHUNT DRIVE


TYPICAL, SEPARATE DRIVE

WAVEGUIDES


CIRCULAR


RECTANGULAR

APPENDIX IV

FILM LIST

FN-8642 Maintenance Safety in Aviation—Murphy's Law (10 minutes). This film shows maintenance personnel some common errors, which cause aircraft accidents by improper installation of equipment. Applicable to chapter 2.

FN-8805 Safety Is No Accident—Ground Safety On and Around Naval Aircraft (16 minutes). This film shows typical unsafe practices which result in accidents on and around aircraft, and gives preventive measures to be taken. Applicable to chapter 2.

MC-6932A Introduction to Physics (10 minutes). This film shows the main division of physics, provides a basic vocabulary for the study of physics, and illustrates some of the important concepts of physics. Stress is laid on the importance of physics in understanding everyday problems. Applicable to chapter 3.

MN-8572 Moistureproofing Electrical "AN" Type Connectors (20 minutes). Shows how to apply a synthetic rubber mix to electrical connections as protection against corrosion, moisture, vibration, shock, and other causes of failure. The process is called "potting." Shows how to prepare the connectors for potting and how to mix and apply the compound. Applicable to chapter 4.

MA-8371 Why Batteries Should Always Be Clean (6 minutes). Shows how to clean a battery to prevent engine failure; washing with solution, and checking electrolyte. Applicable to chapter 6.

MN-8592 Theory of the Lead-Acid Storage Battery (20 minutes). By means of animation, this film shows in detail how chemical energy is converted into electrical energy to produce electromotive force. Applicable to chapter 6.

MN-8594A Direct-Current Generators—Theory of Operation (16 minutes). Shows the basic components of a generator; also explains emf of self-induction. Applicable to chapter 7.

MA-8764R Helicopter Maintenance—Part 9—Generator Systems Troubleshooting (22 minutes). This film is concerned with troubles that may develop in aircraft generator systems, covering the recognition of malfunctions and the procedures for locating trouble spots. Applicable to chapter 7.

MN-8594B Direct Current Motors—Theory of Operation (10 minutes). Shows the basic components of d-c motors and explains their operation. Applicable to chapter 8.

MN-8483A Magnetic Amplifiers—Theory of Operation (18 minutes). Presents the basic theory necessary for understanding magnetic amplifiers. Describes magnetic flux in straight and coiled conductors; the polarity of flux; the effect of open and closed cores, both rectangular and toroidal; and the effect of simultaneously using d-c and a-c windings on a closed core. Concludes with description of the simplest form of magnetic amplifier. Applicable to chapter 11.

MN-6848 Aircraft Ignition Systems—Magneto Ignition (21 minutes). Contains simple description of basic aircraft magneto ignition system, covering briefly theory of electromagnetic induction as it applies to one type of aircraft magneto. Applicable to chapter 13.

MA-7812B Circuit Testing with Meters and Multimeters—Practical Application (33 minutes). This film shows that meters and multimeters are indispensable in the operation, maintenance, and repair of electronic equipment. Applicable to chapter 14.

MN-9580B P3A (P3V) Weapon System Operational Techniques—Electrical, Hydraulic, and Fire Detection Systems (20 minutes). Gives P3A pilots and flight crews a general understanding of how the electric, hydraulic, and fire detection systems function during normal and emergency operation. Applicable to chapter 17.

FN-8048C Instrument Flight Control—The Direct Indicating Magnetic Compass (10 minutes). Explains the errors of magnetic variation and deviation as related to an aircraft in flight. The use of the compass rose for compass swinging is demonstrated. Applicable to chapter 18.

MN-8778 Angle of Attack Indicating System (13 minutes). This film gives a semitechnical explanation of how the angle of attack system works, and tells the steps in preflight checking and operational control. Applicable to chapter 19.

FN-7917 Fuel Quantity Gages: Capacitance Type (13 minutes). This film is designed to show aircraft mechanics how to service fuel quantity gages of the capacitance type; it also explains the theory of operation of these gages. Applicable to chapter 19.

FN-8048A Instrument Flight Control—Diaphragm Instruments (17 minutes). Describes the basic operating principles and mechanisms of the airspeed indicator, rate of climb indicator, and the altimeter. Also explains the action of the pitot static system as used with these three instruments. Applicable to chapter 19.

FN-8048B Instrument Flight Control—Gyroscopic Instruments (14 minutes). Describes the basic operating principles and mechanisms of the gyro horizon, the directional gyro, and the turn indicator. Applicable to chapter 20.

MN-8137 HSS Automatic Stabilization Equipment (17 minutes). Shows theory and operation of this equipment. Applicable to chapter 21.

MN-7831A Care and Use of Handtools—Part 1 An Introduction to Handtools (10 minutes). Discusses choosing the right tool for the job, using it correctly, using it safely, and keeping it in good condition. Applicable to chapter 22.

MN-8411 The NC-5 Mobile Electric Power Plant—Operation and Maintenance (14 minutes). Discusses the functions of the NC-5 Mobile Electric Power Unit and demonstrates a number of "do's" and "don'ts" in its operation. Applicable to chapter 23.

MN-9741A Aircraft Support Equipment—NC-10 Mobile Electric Power Plant (20 minutes). Demonstration of the proper method of operating and servicing the NC-10 power unit while servicing aircraft electronic system during maintenance. Applicable to chapter 23.

INDEX

★ U.S. GOVERNMENT PRINTING OFFICE : 1965 O—773-186